# POLICY FRAMEWORKS

# TO STIMULATE ENVIRONMENTAL TECHNOLOGY

# IN THE COMPUTER AND ELECTRONICS SECTOR

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## EXECUTIVE SUMMARY

**Grant Title**: Policy Frameworks to Stimulate Environmental Technology in the Computer and Electronics Sector, #RA 824752

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### Project Description

The project examined how a sector approach to environmental policy can stimulate cleaner technology in the computer and electronics sector. Using the lens of this sector provides an opportunity to look at policies to address the likely environmental problems of the next century and spur the use of innovative technology in solving them.

<u>Project approach and tasks</u>

The project combined analysis by the principal investigators with discussion and comments by an Electronics Working Group that included members from companies, government, academia, and an environmental group. The tasks included 1) reviewing earlier approaches to environmental technology and environmental policy for sectors and defining use of these terms for the project; 2) identifying the key characteristics of the computer and electronics sector that underlie its relationship to the environment; 3) developing a case study on disk drives to provide grist for discussing policy directions; 4) co-organizing a session on "ecotransformation" of the electronics sector for the Sixth International Conference of the Greening of Industry Network; 5) drafting the policy framework; and 6) serving as an incubator for another project on electronic innovation for climate protection and a limited exploration of material flows. The principal investigators also drew on their participation in the work of the Common Sense Initiative's Subcommittee on the Computer and Electronics Sector.

<u>Defining the terms</u>

While the term *environmental technology* at one point was used primarily to describe pollution abatement equipment, the project chose to define this term and its siblings "cleaner production" and "cleaner technology" to mean technology that offers solutions to social and environmental problems; includes systems and services, software and hardware, products and processes; and is designed to use less material and energy, avoid toxic materials, and reduce risk across media. The project assumed that policies will be most effective if they influence decisions about what technology to develop and how to develop it--the point at which both environmental problems and opportunities can be most effectively addressed with the fewest resources.

The project assumed that a sector policy approach means focusing environmental policies on economic sectors and developing these policies with the participation of the key actors. It assumed three strengths of this approach: 1) It can address the root causes of environmental issues in the decisions that determine the extraction, use, and release of materials. 2) It offers one way to move from a fragmented to a systematic approach to environmental problems at a time when environmental issues are recognized as embedded in all of society's activities. 3) It provides a focus for organizing and implementing policy with broad participation from stakeholders.

At the same time, the project recognized the *limits and challenges of a sector approach* to environmental policy for the computer and electronics sector: The limits include: 1) The sector approach is only one way of focusing policy; it needs to be combined with others, particularly a focus on places; 2) Policies for different sectors are likely to differ in detail and application rather than in basic approach; 3) Ideas for policy and technological innovation will often be developed in interaction with other sectors;. 4) Sectors are difficult to bound. Electronics products are used in almost every other sector of the economy from transport to energy supply. In making them, electronics companies rely on other sectors such as chemicals. 5) Groups affected by policy focused on the sector are not organized to participate effectively in the policymaking process.

<u>Characteristics that underlie the sector's relationship to the environment</u>

To develop sector-based environmental policies requires an understanding of the industry. This is specially true for the fast-changing computer and electronics sector that provides components hidden in cars, appliances, and thousands of other products. One poll of the public found that three-fifths of the respondents had no opinion on whether the sector harmed or helped the environment. To provide a foundation for considering policy options, the project examined four characteristics of the computer and electronics sector that influence its relationship to environmental policy:

- The sector develops and markets new products--intellectual property--in contrast to sectors such as chemicals, petroleum, and pulp and paper that start with natural resources and turn them into products.

- The sector is a leader in the economy and in changing the ways in which business is organized.

- The sector is a complex mix of sources of both environmental degradation and environmental solutions.

- Participation in environmental policymaking is now limited mainly to a few sub-sectors which face environmental challenges at the production stage with some attention to design for environment and managing electronic products no longer in use.

<u>Three approaches to policy frameworks</u>

With the members of the Electronics Working Group, the WRI selected three areas that present opportunities for developing policy frameworks for environmental technology in the computer and electronics sector: 1) design for the environment in new product development, 2) business opportunities in environmental technology, and 3)global product chains.

To gain a more detailed understanding of current practices for incorporating the environmental factor into new product development along a product chain, the WRI project team commissioned a case study of the disk drive chain. This study was carried out by Robert L. Ferrone, a former design engineer with 30 years of experience in the industry. Disk drives were chosen because the manufacture of drives presents opportunities for changes that reduce environmental impacts that can provide a company a competitive edge. At the same time; the short life cycle of drives makes decision points easier to identify. Finally, the disk drive illustrates common characteristics of the electronics sector such as an international scope and the fact that products are built from components developed along a horizontal supply chain. Ferrone interviewed staff at two component makers, a disk drive manufacturer, and a computer maker along the chain.

For the second and third policy opportunities--business opportunities and global product chains--the project served as an incubator. After discussion in the Electronics Working Group and WRI's Climate, Energy, and Pollution Program, the project team narrowed the business opportunities approach to electronics innovation to address climate change. John Horrigan, a consultant who had just completed a PhD in technology policy, prepared a scoping paper that was reviewed by the Electronics Working Group. Under the umbrella of WRI's Climate Protection Initiative, this paper was further developed with business partners through the Electronic Industries Alliance and the International Cooperative for Environmental Leadership. WRI published in July 1998 as *Taking a Byte Out of Carbon: Electronics Innovation for Climate Protection.*

The project team briefly explored using the environmental implications of the global product chains as a policy approach. Trade data on components are available and give some indication of financial flows related to electronic products among countries. Data on material flows in the sector are more difficult to locate beyond the waste data for U.S. electronics facilities regulated by EPA. Under another project, WRI is developing indicators for material flows. A next step will be to address indicators at the sector level, which may provide a further pursue this work.

**Summary of Findings**

1. Participants in a session on the ecotransformation of the electronics sector at the Sixth International Conference of the Greening of Industry Network developed the following (unranked) list of drivers and barriers to "ecotransformation" of the electronics sector.

<u>Drivers of Ecotransformation</u>

- internal company leadership
- rapidly changing technologies and organizational structure
- competition for global markets
- pressure points along the supply chain
- corporate customer demand
- costs of resources and liability
- regulations, particularly emerging "take back" policies

<u>Barriers to Ecotransformation</u>

- short attention span for issues peripheral to technology development
- rapid obsolescence of products, production equipment, and people
- environmental issues not addressed at a strategic level
- little awareness of sustainability issues in companies
- a primary focus in companies on reducing costs
- weak internal relationships between environmental and product development groups
- multiple suppliers of components along supply chain
- lack of strong customer relationships
- large energy demands for transport in global supply and distribution chains
- efficiency gains may be offset by growth in production

- lack of clear public environmental goals
- lack of market pull from customers
- missing players in debate--software, transport, services, consumers

2. The prime characteristic of the computer and electronics sector is its focus on developing and delivering new technology to the market rapidly. Policy frameworks to stimulate environmental technology in this sector need to influence decisions about what to make and how to make it and resolve the mismatch between the business product development cycle and the physical life cycle of products.

3. The disk drive case study found:

- As of the mid-nineties, companies in an example disk drive chain were offering training courses in design for environment and company engineers were taking some initial steps to improve the environmental characteristics of products.

- The primary responsibility of company environmental departments was ensuring compliance with environmental regulations.

- Reviewing a product design to identify business opportunities through superior environmental performance was not a primary function of the company design teams.

- Within companies, the communication between marketing and the design and environment teams was quite limited.

- Product designers focus on the unit cost of production, time-to-market, product performance and reliability, and compliance with environmental regulations. They lacked the tools and information to analyze environmental impacts and costs in any depth.

- Customer and supplier companies along the chain communicate by the customer's providing technical specifications and environmental regulations to the supplier. Suppliers are not brought into discussion of environmental issues at an early stage nor given clear environmental priorities beyond regulations.

Companies need to incorporate the environmental concerns in the concept stage of product development so that environmental issues are considered as materials are selected and the manufacturing process and packaging are developed. Means of recycling or reuse, for example, would be considered at this stage. To enable the necessary trade-offs in design and costs engendered by environmental considerations, the new product development team would be headed by the business manager and include the finance manager. Rather than disbanding the team after the product is launched, it would be reconstituted and continue to function .

4. While it faces environmental challenges, the computer and electronics sector is unique in the potential its technology offers for solving environmental problems. It has enabled information to become a primary environmental policy tool. Its technology can both improve the efficiency of buildings, office equipment, and transport and substitute for material and energy through electronic communication and virtual reality. The scale of these opportunities needs to be better defined.

**Conclusions**

The longer-term vision of ecotransformation of the computer and electronics sector is to redefine the sector in terms of delivering value and service over the life cycle of a technology rather than competing on time-to-market with new products. Key elements in a policy framework to move toward that vision include setting ambitious environmental goals, funding research, developing public metrics to track progress, improving tools to leverage the supply chain and stimulate market demand for environmental technology, and building broader participation into both using technology to protect the environment and participating in policymaking for the sector.

**Web Site:** See http://www.WRI.org

**Publications**:

John Horrigan, Frances H. Irwin, and Elizabeth Cook, *Taking a Byte Out of Carbon: Electronics Innovation for Climate Protection,* Washington, D.C.: World Resources Institute, July 1998.

## POLICY FRAMEWORKS FOR ENVIRONMENTAL TECHNOLOGY IN THE COMPUTER AND ELECTRONICS SECTOR

### Introduction

As it merges with communications, the computer and electronics sector is poised to join biotechnology and lead the economy of the next century. In developing the next generation of environmental policy, much attention focuses on pollution-producing sectors of the past century: chemicals, petroleum, automobiles, iron and steel, and pulp and paper. Traditional environmental priority-setting criteria, based on the types and amounts of pollution and wastes from production processes, put the focus on these sectors. Using these criteria, a few important sub-sectors of electronics such as semiconductors and printed wiring boards have also become priorities for environmental protection. In contrast, the complex mix of opportunities and challenges that the computer and electronics sector raises for environmental policy has received less attention even as the sector's technology turned public, standardized information into a powerful environmental policy tool. Looking through the lens of this sector of the future, the World Resources Institute (WRI) project examines how policy frameworks can stimulate technology that helps move toward sustainability in the 21st century.

### 1. The Project Approach

The project combined staff research and analysis with advice from a broad-based Electronics Working Group convened by WRI. It also drew on participation in the U.S. Environmental Protection Agency's regulatory reform projects, particularly the Subcommittee on the Computer and Electronics Sector of the Common Sense Initiative.

The terms "environmental technology" and "sector-based policies" have been used frequently in the past decade, but neither has a widely accepted meaning. Thus an early--and continuing--piece of the project was to review the development of these two related terms and clarify their meaning for the project. This work is summarized in section 2 and the sources detailed in Appendix A. Similarly, staff explored the literature on the technology, organizational practices, economic role, environmental issues, and players in the computer and electronics sector. Four characteristics of the relationship between this sector and the environment derived from this exploration are outlined in section 3.

A primary focus of the project was to identify the drivers and barriers for incorporating environmental goals into technology developed in the computer and electronics sector. To do this, WRI organized an Electronics Working Group, which met once in 1996 and twice in 1997 and also maintained email contact. Appendix B lists members of the Group and also includes the meeting agendas. Members shared information about sector approaches to environmental technology and the electronics sector. Much of the discussion about environmental policy and the computers and electronics sector is either very general or caught up in the specifics of implementing existing legislation. The project sought to work mid-way on the spectrum between these two extremes. To provide grist for the discussion, the Electronics Working Group designed and reviewed a case study of the practice of design for environment in the disk drive product chain. The results of that work are found in Section 4. The Greening of Industry Network's International Conference in November 1997 provided another opportunity to identify drivers and barriers. With Patricia Calkins of Xerox Corporation, project investigator Frances Irwin chaired a session at which about 30 participants outlined one set of drivers and barriers for "ecotransformation" of the electronics sector. Section 6.1 and Appendix C describe that session.

In addition, the project and the Electronics Working Group served as the incubator for a project on business opportunities for the electronics sector in climate protection that was then pursued separately under the WRI Climate Protection Initiative and is described briefly in Section 5. The project also explored the possibilities of tracking materials flows associated with product flows in the sector.

The suggested elements of a policy framework for stimulating environmental technology in the sector outlined in Section 6.2 emerged from findings of the disk drive case study, the related project on electronics innovation for climate protection, and experience with other projects on electronics innovation for climate protection and tracking materials flows. The framework also draws extensively on discussions in the WRI Electronics Working Group.

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## 2. Defining a Sector Policy for Environmental Technology

The terms "environmental technology" and "sector policy" are both applied to a range of activities. After a review of the literature, WRI and members of the Working Group chose basic insights about the meaning of these terms to serve as the foundation for the project.

### *2.1 Environmental technology*

The term "environmental technology" and its close relatives "cleaner technology" and "cleaner production" have roots in the early 1970s. Their shades of meaning have varied in the 25 years since. This project identified four threads running through the literature as basic to the project's understanding of environmental technology.

- *Technology responds to market and societal demand.* The literature stresses that technology is driven by demands in the market and in society. It raises questions such as how society develops environmental goals and how these are most effectively applied to influence innovation. Stuart Hart, a business professor, looks at the question from a firm's view. In his presentation of a sustainability portfolio, he suggests companies ask: "Does our corporate vision direct us toward the solution of social and environmental problems?" [1] In the United States, environmental groups and states have led a push toward pollution prevention. Some business leaders and NGOs such as Greenpeace are engaged in different aspects of moving European companies and countries toward cleaner production.

- *Technology includes systems and services, software and hardware, products and processes*. Much of the current generation of environmental policy focuses on production processes and waste management equipment. This project chose to assume the importance of the current regulatory system for production processes (and the need to improve that system) but to focus on computers and electronics technology--particularly as products or product systems, whether software or hardware or services, that society uses in homes and offices, transport, and communication.

- *Environmental technology encompasses designing and using products or systems to carry out society's activities in ways that use less material and energy, avoid toxic materials, and reduce risk across media*. This project chose to equate environmental technology with the UNEP definition of cleaner production and products. It calls for conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and toxicity of all emissions and wastes before they leave the process. It covers the entire life cycle of the product from raw material extraction through disposal of the product.[2]

- *Environmental technology policies are most effectively applied at the source and are developed with an awareness of the entire product cycle upstream and downstream of manufacture*. The project chose to focus on policies that relate to products at the early stages of concept and design and lead to more sustainable product and materials cycles both upstream and downstream from the manufacturing stage.

The project addresses the environmental component of the sustainability concept. It assumes that to be effective environmental policy must be implemented within a broader framework that includes not only the economic aspects but also social issues, such as equity among demographic groups and communities and worker health.

### *2.2 Sector policies*

A sector approach as used in this project builds on work carried out in Europe and in the United States. Internationally, the sector approach evolved as a means of focusing and implementing environmental policy at the source in a way that is integrated across media and along the product cycle. *Our Common Future*, the report of the Brundtland Commission, stresses that to address the increasingly complex and interrelated nature of environmental problems, environmental policy must focus on the agents and activities that cause the problems--that is on the sources of environmental effects in the decisions of private sector and governmental institutions. The Netherlands has demonstrated how an environmental policy plan can be applied through negotiated performance agreements with sectors of the economy that support adoption of improved technology.

The project also drew on EPA's increasing experience with sector approaches. In contrast to the Netherlands, where sector work has involved the economic and environmental ministries and a top-down as well as bottom-up approach, experiments in the United States have been led largely by EPA or non-governmental organizations such as the Environmental Defense Fund. EPA's Common Sense Initiative convened a Subcommittee to address regulatory reform in the computer and electronics sector. EPA's compliance and enforcement office has perhaps come closest to institutionalizing a sector approach by organizing its work increasingly around sectors and preparing notebooks that lay out the sector's baseline compliance record and suggest pollution prevention alternatives for key processes. One of these covers some parts of the computer and electronics sector.[3]

The project assumed three potential advantages of a sector approach.

- *A sector approach increases the opportunity to get at root causes of environmental issues in economic decisions* that trigger extraction, use, and release of materials, energy, and water--the carriers of environmental damage. Getting at root causes offers the opportunity of both avoiding much waste and emissions and at the same time creating products that directly address environmental challenges of degraded resources. In business, getting at the source means involving the market, design, finance, and business unit managers as well as the environmental managers.

- *A sector approach offers one way to frame a more systematic approach to environmental issues.* In the current generation of environmental policy, each problem is treated separately. As problems become more complex and interrelated, a broader approach is likely to be more effective in moving from addressing the symptoms to changing activities and avoiding the problems.

- *A sector approach can lead to policy that works.* Policy that is based on better information and negotiated with those who will carry it out is likely to be well-conceived and implemented more successfully, assuming that all parties can be effectively engaged.

However, the sector approach to policy also has limits.

- *A sector approach needs to be combined with other policy focuses* on the source such as substances, products, and facilities and implemented in relation to policies aimed at ecosystems or places. It is not the only focus for environmental policy.

- While policy may be tailored to the characteristics of a particular sector, *basic environmental policies are unlikely to differ significantly across sectors*. A reporting system developed for the electronics sector should be generally appropriate to other sectors, for example, though some issues may be more important in one than another. Measuring diffuse sources is an issue for petroleum refineries, while identifying the baseline of the amount of electronic equipment that needs to be recycled is on the agenda for computer and electronics companies.

- Sector policy focused on promoting adoption of environmental technology needs to recognize that *ideas for innovation often come from outside a sector*. Electronics technology itself is a primary driver of innovation in other sectors such petroleum and pharmaceuticals and in turn the electronics sector learns from companies that use its equipment, such as freight and mail order companies that have taken the lead on tracking packages in transit and other logistical systems.

- *Defining "who" constitutes the sector is not a straightforward task*. Particularly for the electronics sector, the boundaries are not easy to draw as electronics technology plays increasing roles in other parts of the economy from entertainment to medicine. Other sectors such as chemicals are suppliers. Arranging participation in policymaking is also challenging because some influential players (software or transport) may not be at the table because their interests are not clear or they are not organized (consumers). Also, given the global nature of the sector, participants from the community to the international level often need to be involved.

The concepts of environmental technology and sector policy have developed separately although they increasingly intersect. Common elements are getting at the cause of environmental problems, taking a systems approach, and involving a much wider range of decisionmakers from government, industry, and civil society. To gain a sense of how a sector approach might promote environmental technology in computer and electronics, the project first took a broad look at the characteristics of the sector and then made a more in depth analysis of design for environment practices in an example product cycle.

## 3. Four Characteristics That Underlie the Relationship of the Electronics Sector and the Environment

The relationship between the environment and the computer and electronics sector is not well understood for at least three reasons. One is the rapid pace of change. It is hard to connect the sector with the environment when it is nearly impossible to keep up with the ways the technology is developing and changing daily life as chips become ubiquitous and as voice, data, and visual communication merge and become portable. Even the industrial classification system is struggling to keep up. Beginning in 1999, a North American Industry Classification System will introduce a new framework with a much more detailed breakdown of information and communication hardware and software. This project used the term electronics broadly to include software, consumer electronics, computer hardware, electronic components, and communications equipment.

Second, beyond consumer products, many electronics and communications technologies are by their nature enablers, such as the electronic controls that help motors run more efficiently in automobiles and appliances. While Intel's advertising campaign has made microprocessors visible inside computers, most electronic components remain invisible. Their environmental benefits, such as increasing energy efficiency or meeting needs with less material, are largely unseen. So are the environmental problems posed by the use of hundreds of toxic chemicals used in some portions of the sector.

Third, unlike sectors such as agriculture and power production, with long histories of organic agriculture and renewable energy movements, or chemicals, which experienced a generation of heavy environmental regulation, a sustainability vision of the computers and electronics sector is lacking. Public knowledge of environmental issues in this sector is scant enough that *USA Today* published a series outlining the history of environmental issues in the semiconductor industry in 1998. It used an editorial to remind communities competing for the jobs and taxes provided by semiconductor manufacturing facilities to pay careful attention to ensuring worker health and environmental pro*tection when economic development efforts bring new fabs to their communities.[4]

To increase the project team's understanding of the relation of the computer and electronics sector to the environment, WRI explored four characteristics of the sector that underlie this relationship: 1) a developer of technology rather than a user of natural resources; 2) a change agent in the economy and business organization; 3) a source of both environmental problems and solutions; and 4) a sector composed of a broad range of interests, many of them unorganized to participate in policymaking.

### *3.1 Developer of new technology rather than a processor of raw materials*

The still young computer and electronics sector is defined and *driven by technology*. Delivering new products is the focus; everything else is secondary. Innovation--faster, cheaper, smarter--is the mantra. Prestige belongs to company engineers, marketers, and investment firm partners. The lawyers tangle over intellectual property. Product cycles for the chips in computers are 18 months; Internet product cycles may be as short as three. In starting with the technology, the electronics sector differs from steel, pulp and paper, or chemicals sectors based on specific natural resources--iron, timber, and petroleum. These sectors use technology to convert these resources into products. These sectors, too, are changing as information technology shifts the way they do business. Still, growth is usually equated with shipping larger volumes of materials while in electronics it is increasing the value of intellectual property in products that matters.

Electronics technology also relies on specific materials--particularly silicon, chemicals (used in making chips), plastics (for housing products), and metals (in displays and power management). The virtual world relies on the physical world. However, electronics is much less tied to volumes of specific materials. The sector's growth comes from using fewer materials to provide greater power and more connections at less cost. Success is measured in new products shipped rather than in volume. The computer industry obtained 78 percent of its revenues from products on the market for two years or less as of 1995, up 7 percent in five years.[5] (In comparison, even for a leading chemical company, the percentage is not likely to be above a quarter of revenues from new products.) The question is whether the environmental costs of the sheer numbers of increasingly powerful new, smaller products and the activities they stimulate will overwhelm the impressive reduction in material and energy intensity computer and electronics provide.

The sector is also *young*. Compared to agriculture, it is an infant. The semiconductor just celebrated its fiftieth birthday. The personal computer gained wide use only in the last 15 years. Just in the last three years, as the Internet has emerged from its more elite research use, the sector has begun to merge with telecommunications. One consequence of the sector's youth is that environmental issues just began to be addressed on a sector level in the early 1980s. Now, both the environmental problems and opportunities are changing as the technology develops at a headlong pace and the economy shifts more and more to services.

The sector's *pace* of development and growth has been extraordinary. Hewlett Packard grew from a garage to a $50 billion dollar company in 50 years. Segments of the industry also have exhibited spectacular growth. Disk drives, which store information in computers and other devices, provide one example. The capacity of disk drives has grown an average of 35 percent a year for 20 years. In the ten years between 1984 and 1994, the number of disk drives shipped went from a few thousand to 60,000, notes Disk/Trends. Between 1976 and 1995, 129 firms entered the market; 20 are still operating. As 1997 ended, seven companies fought for the rapidly growing and changing market for electronic data storage.[6] Similar examples of expanding markets and fierce competition can be found in other segments of the sector. Printed circuit or wiring board companies have grown from an output of $1 billion in 1975 to $22.8 billion in 1994. The number of companies shrank from about 2000 to 900 from the mid-eighties to 1994.[7] Because manufacturing equipment for printed circuit boards becomes obsolete in 18 to 36 months, the companies have lobbied Congress to change the tax code to reduce the time in which they can recover costs for capital investment in equipment from five to three years.[8]

Electronics technology is the *key to helping other sectors operate more efficiently*. John Browne, CEO of British Petroleum (BP), joined Intel's board, reflecting the interest of older, resource-based sectors in electronics technology and the role it is already playing in increasing returns in oil exploration.[9] In pharmacology, robochemistry is applying computerization to drug research. Ink-jet printer technology has been adapted in miniaturized mass screening processes, for example.[10] In the automobile industry, cars are now designed using computers. The finished products often contain hundreds of chips. No one knows just how the technology will develop next and what applications will become most important. Microsoft's technology futurist suggests that the real impact of the information revolution may not be apparent for another 50 or 60 years. He expects what has happened so far will be very small in comparison to what lies ahead.[11] In contrast, economist Paul Krugman is doubtful about future growth of the technology and its impact on the economy. He expects that Internet growth will slow drastically and "ten years from now, the phrase *information economy* will sound silly."[12]

The last generation of environmental policy was developed to a large extent based on assumptions of mature technology using mass production to turn natural resources into products--the antithesis of the computer and electronics sector in the 1990s. It targeted pollution and waste at large industrial sites, such as refineries, where the technology often had not changed much for decades, and fuel emissions from cars with a life cycle of 6 to 10 years. The next generation of policy is developing in an era led by the computer and electronics, communications, and biotechnology sectors. It is focused on technology innovation in which rapidly changing products emerge from constantly shifting chains of companies operating around the world.

### *3.2 Leader in the economy*

Few question that electronics and communications will join biotechnology in dominating the economy of the 21st century. *Business Week* already puts high technology at ten percent of the U.S. gross domestic product. It estimates sector output at $420.3 billion for 1996. That is close to twice the level in 1988 with much of the growth occurring since 1993. This figure for high technology includes business and consumer spending on computers and communications equipment, net exports of information technology, consumer spending on telephone service and cable television, and investment in telecom structures.[13] A Department of Commerce study of the digital economy estimates information technology (defined as computing and communications) will be at 8.2 percent of the Gross Domestic Product for 1998, up from 4.9 percent of the economy in 1985.[14]

High technology employs over nine million people with about 60 percent of the jobs beyond the core computer, software, and communications industries in high tech sales, repairs, management consulting or temping, programming, or providing technical back-up for networks in other parts of the economy.[15] The Department of Commerce puts the number employed in high technology at 7.4 million in 1996. They earn an average of nearly $46,000 a year compared to $28,000 for the private sector as a whole.[16] The American Electronics Association has analyzed employment in electronics and information technology at the state level. Using preliminary 1996 data, California ranked at the top with more than 724,000 workers earning an average of $55,160 a year in wages and benefits.[17] While the electronics sector is the largest U.S. manufacturing employer, the number of sector manufacturing workers is declining as facilities automate. Growth is in software, communications, management consulting, temporary services and jobs that did not exist a few years ago. In four years, for example, SmithKline has gone from two to 70 bioinformaticians, who use software to analyze data about gene function used in developing new drugs.[18]

If equated with high technology, the sector also takes the lead in U.S. trade and international investment. U.S. high technology exports for 1996 reached $150 billion followed by transportation equipment at $102 billion and chemicals at $60 billion. High technology invested about the same amount as the chemicals sector outside the United States in 1995: $69 billion and $68 billion respectively.[19] Similarly, the electronics industry has become central to many Asian economies. The Philippines provides just one example. The sector has provided the highest export revenues since 1981. In 1993, the sector accounted for one-third of all export earnings. In 1996, they were more than half at over $10 billion. In 1993, the sector employed 75,000 people in the Philippines.[20] The collapse of the Asian economies, of course, means these figures will be quite different for both the United States and Asian countries in 1998.

Aside from its size and its importance in trade and investment, this sector is an economic leader for another reason. Its companies are changing the way the economy is organized and other sectors are beginning to copy its risk-seeking business culture. New jobs across the U.S. economy have come from rapidly growing firms funded by venture capital. At the same time, larger firms are being broken into smaller units or decentralized. These firms join the constantly changing product chains that characterize the sector. Notes a business leader: "Electronics companies are uniquely systems-oriented. Almost no firm manufactures from the ground up a stand-alone product. A company either draws on other people's components or makes products that fit with other people's products into a system."[21]

Initially, computer companies were organized vertically with IBM, Digital, and others all making chips, computers, operating systems, application software, and handling distribution. By the early 1990s, the structure had shifted. Companies were competing horizontally for business in each of these areas. Along the product chains, some firms focus exclusively on design. Others manufacture components, and still others assemble the parts into sub-components and components and manufacture and distribute products. One example of this horizontal differentiation can be seen in the makers of printed circuit boards, the surface for mounting electronic components and providing electrical interconnections for computers and many other products. The boards are designed by one company, made by another, and assembled by a third. The importance and roles of players on the chain has changed over time. Until 1980, original equipment manufacturers accounted for more than half the output of the boards. By 1994, more than 80 percent of U.S. output came from independent companies. By 2000, half the boards may be purchased by contract asemblers, making these companies a key point on the chain from an environmental perspective.[22]

Alliances are frequently made--and changed--among companies along the chain to share the costs of developing new ideas and to turn them into products or enter a new market. Competing companies may share the several billion-dollar investment in a fabrication facility for chips, for example. During a 12-year lifetime, the fab goes through three or four changes in equipment. Many companies just design chips and have other firms make them. Computer companies increasingly outsource most manufacturing.

All sectors are difficult to bound. That is particularly true for electronics. For example, one important part of the supply chain for chip fabricators is the chemical industry. The U.S. demand for electronics chemicals is expected to grow at 8.5 percent a year to $4.6 billion in 2001. It is not a huge volume market for the chemical industry but it is growing. It requires high investment in research but the profit margins are also higher.[23] The chemical industry also intersects the electronics industry in other stages of the product stream. For example, the market for color toners for computer printing and photocopying is expected to grow at 40 percent a year through 2001, creating a market for raw material suppliers.[24] Even with the Asian economic crisis, electronics chemicals for semiconductor companies were growing at 7% a year.

The sector is also difficult to bound geographically. Firms serve customers around the globe from regional clusters in Asia, Europe, and North America. Silicon Valley is the prime example of a regional concentration, with thousands of companies operating in a decentralized industrial system integrated through networks, technology agreements, and joint ventures. The product chain is seldom limited to one region, however. A disk drive chain starts with the parts and component makers of semiconductor chips and cables, goes to the disk drive manufacturer, and ends with computer manufacturer and distributor. Design may take place in the U.S., manufacture in Malaysia, and final assembly back in the U.S.[25]

Future environmental policy needs to take into account changing forms of business organization, particularly product chains that often extend around the globe. The changing forms raise questions including: Who will take responsibility for the environmental factor and how will information be communicated along the chain? How will users of the product know what environmental characteristics have been incorporated? Will comparable statistics be developed internationally to match the global nature of product supply chains? What opportunities does a global market offer in using leapfrog technologies to solve environmental problems? What forums--with what representation of government, business, and NGOs--will take the lead in developing environmental goals and means to track them?

### *3.3 Both a cause of and a solution to environmental problems*

Neither the environmental problems of the sector nor the solutions that the sector's technologies may provide are widely understood. Fifty-nine percent of those responding to a public opinion survey on environmental protection said that the electronics sector neither causes nor solves environmental problems. Among those with an opinion, more think the sector has potential to solve environmental problems than any other sector. About twice as many (23 percent) put it in the category of solving problems as causing problems (12 percent). In contrast, the chemical sector, an important supplier for the electronics sector, ranked first (80 percent) as a sector thought to cause environmental problems.[26]

#### 3.3.1 A cause of environmental problems: The physical reality of the virtual world

At first, the growth of the computer and electronics sector was widely viewed as a clean alternative to the existing smokestacks of iron and steel, petroleum, and chemicals. This began to change as the industry encountered a series of environmental problems leading to increased legislation and court suits. Many of these problems related to the intensity of use of toxic chemicals, water, and energy in the manufacturing processes for semiconductors. One estimate, for example, puts the processing requirements for a *single* 150 mm. silicon wafer used in making chips at 285 kWh of energy, 250 pounds of atmospheric gases, 63 pounds of liquid chemicals, 7 pounds of hazardous and 82 pounds of non-hazardous waste, and 2,800 gallons of water.[27]

- *Groundwater contamination*. In the early 1980s, Santa Clara County residents in California began to find their groundwater was contaminated with solvents used to clean semiconductor chips. The home of Silicon Valley, Santa Clara County topped the national Superfund list issued later in the decade with 29 sites, four-fifths of them related to the electronics industry. Contaminated water remains an issue in Silicon Valley at 150 sites. With much of the industry located in California and the Southwest which depend on groundwater supplies, concern about contamination has been followed by a focus on reducing the large amounts of water used.[28]

- *Toxic releases*. The experience developing local and state building codes and legislation in California to address toxic chemical use and releases in the electronics industry was one root of the Toxics Release Inventory, established by federal law at the national level in 1986 to track releases and waste transfers from industrial facilities for the public. By using water-based solvents, eliminating or minimizing the need for cyanide in plating, and using chemicals more efficiently 208 electronics facilities reduced their releases by three-quarters between 1988 and 1994 as part of EPA's program aimed at halving release of 17 chemicals of particular concern on the Toxics Release Inventory (TRI).[29] TRI data present only part of the picture of reductions in the product chain. The TRI applies only to releases and waste transfers of some chemicals. It does not include chemicals in products that may be released during disposal. Nor does it account for releases in other countries, with the exception of a few companies like IBM that now voluntarily track releases at all facilities regardless of location. In addition, many companies now outsource most of their manufacturing to other companies so tracking reductions becomes more difficult.[30]

- *Ozone depletion.* Electronics firms used chlorofluorocarbons (CFCs) in cleaning processes. and were leading emitters in some communities. To implement the 1987 Montreal Protocol goal of phasing out these ozone-depleting substances by 1996, companies worked with EPA to find and share information on substitutes for these materials, which were used for cleaning components. Lead companies phased out use three years early as they developed a no-clean process that also cut energy use and reduced air emissions and use of lead significantly.[31]

- *Worker health*. Worker health issues, such as exposure to glycol ethers, also emerged. Long a concern to health authorities because of use in other sectors, reports of problems began to surface in the mid 1980s in the electronics sector. Many electronics sector companies began phasing out their of this chemical after an IBM study in 1992 showed a high ratio of miscarriages among women exposed to ethylene glycol ethers in the electronics industry. However, lack of adequate data on worker exposure to the many chemicals used in the industry continues to be a significant source of disagreement between companies and worker and community groups.

By the early 1990s, two other issues had emerged: disposal of products and climate protection.

- *Obsolescent products as waste*. Both the sheer numbers of electronic products entering the market and rapidly becoming obsolescent and their contribution of hazardous materials to the waste stream caused concern. In a 1997 study, updating a first survey in 1991, Carnegie Mellon's Green Design Initiative put the number of personal computers that will become obsolete (more than five years old) between 1985 and 2005 at 325 million. It estimated 55 million will be landfilled and 143 million recycled with nearly half remaining in storage [32] As batteries are increasingly recycled, electronic products become a significant source of hazardous materials in the waste stream. Minnesota estimates that electronic products are now the largest source of lead with about 1,000 tons of lead entering waste management in the state annually.[33] Some companies have initiated voluntary efforts to recycle equipment and materials. In 1996, the President's Council for Sustainable Development called for a shared approach to product responsibility. An EPR2 Roundtable was established as an independent body to focus on end-of-life management of electronic products in 1997 as one outcome of EPA's Common Sense Initiative. The strongest action comes from European countries. Building on initiatives in members such as the Netherlands, Sweden, and Germany, the European Union is expected to issue a final directive requiring its member countries to set up programs giving producers the responsibility to ensure recycling of electronic products and phase out use of four toxic chemicals in these products.[34]

- *Climate change*. Concern about climate change raises several issues for the computer and electronics sector. Some facilities use long-lived greenhouse gases such as perfluorocarbons in manufacturing. Semiconductor manufacturers agreed to reduce their emissions of these materials in a memoranda of understanding with EPA in the early 1990s. These gases were included in the Kyoto Protocol negotiated in 1997. Growing energy consumption is also an issue for semiconductor facilities.[35] The highest use of energy, and therefore concern about greenhouse gas emissions, however, is that resulting from use of electronic products. In the early 1990s, EPA put the computer use by computer systems at 5 percent of commercial electricity consumption with an estimate that it might reach 10 percent by 2000.[36] One result was the Energy Star Program under which companies work with EPA to set voluntary levels of energy use for electronic equipment in "sleep" mode. Companies have reduced energy consumption of products, often dramatically, under this program. Increase in use of equipment, however, means electronic products are still the major source of growth in energy use in homes and offices.

### 3.3.2 Using the sector's tools to anticipate environmental issues

As global competition increased and the consequences of reacting to environmental problems became clearer, leading sector firms were eager to get ahead of environmental issues. Electronics companies adapted to for environmental purposes the tools they use in planning and delivering the sector's technology and communicating with the financial community. These include "design for x", roadmaps, performance standards, and public company reports. At the same time, some portions of the environmental policy community began focusing on new tools to stimulate prevention, reduce use of toxic chemicals, and to integrate environmental policies using goal-setting and public reporting as primary policy tools.

Sector engineers took a lead role in applying the "design for x" engineering approach to environmental issues. Because as much as 80 percent of the costs and materials involved to make a product are determined at the design stage, designing the environment into the product has the potential to save money by avoiding environmental problems at the beginning of product development. By 1998, the Institute of Electrical and Electronic Engineers (IEEE) was sponsoring a sixth International Symposium on Electronics and the Environment.

Sector consortia and trade groups also began preparing a round of environmental, health, and safety roadmaps, building on experience with technology roadmaps that laid out the steps, timing, and responsibilities for developing the sector technologies. The first was prepared by the consortium SEMATECH. As part of a much larger amount aimed at increasing the competitiveness of the semiconductor industry, SEMATECH received $10 million from the Department of Defense to develop environmentally safe microchip manufacturing processes.

Community groups lobbied for this provision. The semiconductor industry has continued to develop roadmaps with the most recent completed in 1998.

With funding from the Department of Energy, the Advanced Research Projects Agency, and EPA, The Microelectronics and Computer Technology Corporation (MCC) organized preparation of an Electronics Industry Environmental Roadmap in 1993. The roadmap was aimed at a strategic, industry-wide approach to environmental issues. It argued that integrating environmental consciousness through management systems and processes was more effective than responding to piecemeal initiatives and relying on end-of-pipe solutions. Incorporating environmental consciousness into corporate strategy would contribute to longer-term competitiveness. The roadmap built on an earlier initiative to identify the principal sources of waste in computer production and use. It focused on three parts of the manufacturing process shown by the earlier report to be priority environmental issues: semiconductors, printed wiring boards, and display screens. By the time the MCC consortium issued a second Electronics Industry Environmental Roadmap in 1996, a half dozen sub-sectors had prepared their own roadmaps addressing environmental issues related to the evolution of particular technology. The second MCC roadmap took a broader approach looking at business opportunities, information and knowledge systems, design for environment, product disposal, and emerging technologies.

Sector companies also began to develop industry performance standards related to the environment. Performance standards are a basic tool in the sector because they allow many different companies to design and produce different parts of the product simultaneously--to take a modular approach. IBM took the lead in developing an international environmental management system through a private international standard-setting body--ISO (International Organisation for Standardization). Another half dozen standards on issues such as life cycle assessment and labeling also entered preparation. The ISO process raised issues still being addressed about appropriate forums, processes, participants, and approaches to setting standards in the environmental arena.

Some of the larger electronics and communications companies including AT&T, Intel, and IBM also began to issue public environmental reports or to include environmental issues in their financial reports. United Technologies Corporation set reduction goals for all its facilities in its report issued in 1998. A few U.S. facilities issue their own reports. SGS-Thomson, for example, puts out reports at the facility level as part of its participation in the Eco-Management and Audit Programme initiated in the European Union.

The environmental results of these initiatives by electronic companies are not yet clear. . Environmental management systems with goals and commitment to public reporting are just being put in place by lead companies. It is not clear how supply chains will be covered in most cases. Design for environment has spread among engineers but is not yet the corporate strategy envisioned by the MCC Roadmap. Roadmaps are clearly playing an important role in addressing some environmental issues internally in some segments of the sector, such as printed wiring boards and semiconductors. However, standard public reporting has not been a part of the roadmap process. Thus the results are not widely known. Since 1996, most of the initiative has been at the sub-sector or company level. Attempts to synthesize industry and approaches by government and environmental groups have made limited progress through projects such as the Common Sense Initiative. That Initiative has spun off the EPR2 Roundtable, come up with a list of principles for community and worker engagement, a step toward recycling lead-containing cathode ray tubes, and made some progress in integrating reporting. Participants have found it time-intensive and slow to produce results given conflicting expectations of quick relief among most business leaders and move toward longer-term sustainability among some other participants.

### 3.3.3 Using the sector's products to solve environmental problems

The electronics sector has an edge over other sectors in approaching the environment as an opportunity to provide solutions as well as overcome problems. The Wirthlin poll mentioned earlier showed nearly a quarter of the public recognizes this opportunity. Energy consumption remained about constant in the United States as Gross National Product grew by 35 percent between 1973 to 1986. Since that time energy intensity has continued to decline though total use has grown.[37] The electronics sector has driven this trend. So far, however, this advantage has been assumed at a broad level rather than deliberately pursued and documented.

No broadly-accepted categorization of the ways in which electronic products can protect the environment has been developed. However, there is general recognition that by replacing material with information or by increasing the efficiency with which material and energy are used, electronic technology can avoid some damage caused as material is extracted from the earth or dissipated after use.  It can do this in at least four ways:

- *Replacing some uses of material by performing the function a different way*.  Virtual worlds, that allow new products to be designed and tested in less time and at less cost, use fewer physical materials.  Ford Motor Company is working with IBM to speed its product development cycle by using computer design to reduce the need for physical prototyping, which will also save raw materials.  Pharmaceutical companies are drawing on integrated circuits and microprocessors in electronics to create mini-labs.  The new processes reduce drug screening time from four to two years and reduce costs, mostly by reducing amounts of chemicals used in testing by factors of 10 to 100.[38]

- *Miniaturizing products.*  Electronics technology reduces use of materials by providing more capacity with less material.  IBM's disk drives that store information illustrate miniaturization. IBM's new disk drive holds the equivalent of one million printed pages, a stack as tall as a 62-story building, and doubling this capacity is on the horizon.[39]  The first IBM disk drive in 1956 weighted a ton and stored five megabytes of data.  Just over 40 years later IBM produced a disk drive that weighs less than a AA battery and stores 340 megabytes.[40]

- *Increasing the efficiency with which materials and energy are used*.  IBM's copper chip technology requires 20 percent less energy than the previous technology that used aluminum. Because it allows heat generation, will also allow further miniaturization of electronic components.[41]   Electronic equipment serves as the brain in elevators, aircraft, and automobiles so that energy is used more efficiently.  Global positioning systems help an auto driver or an aircraft pilot to take the most efficient route to his or her destination or a farmer apply the just the right amount of fertilizer in the right place in a field.  Electronic controls reduce the energy needed to heat, cool, and light homes. Partners in EPA's Energy Star Buildings Program are expected to reduce their energy use by an average of 30 percent.  Electronic technology plays a key role in these reductions.[42]

- *Replacing some energy-intensive physical transport of people and information with electronic communication.*  Email, videoconferencing, and networking can reduce energy use and pollution as well as the cost and time needed for travel or delivery services.  Just driving across Manhattan requires about 1.5 kilowatts and an hour's time. Information can be sent from Manhattan across the country to San Francisco instantly using one-hundredth the energy.[43]

Recently, a few companies have begun to describe ways in which their products can solve environmental problems. Siemens issued Technology for the Environment in 1997, a brochure that describes 60 products that either directly serve environmental protection or have environmentally compatible features. The first category includes products that protect water or soil, handle waste or recycling or measure emissions, or provide environmental software. The second category of products includes those that are recyclable, resource conserving, energy saving, or result in reduced emissions. They are presented as examples from Siemens' 60,000 product families. IBM went a step further toward casting its products as helping solve environmental problems in its 1997 report. CEO Louis Gerstner introduced the report saying: " . . . information technology is a powerful tool for taking on the world's environmental problems. We are working hard to lead the way in supporting the necessary and desirable solutions."[44] It cites examples of how its technology is communicating and sharing environmental information; stimulating solutions in ways that save resources; and making information technology itself more efficient. Although it does not note the potential environmental benefits, Cisco Systems reports in a piece on its website that the company is saving millions of dollars in printing costs as it has switched its ordering system to the Internet.

A few analysts are looking at both the opportunities for and challenges to economic sectors in moving toward sustainability. In examining how industrial sectors are liking to fare in a move toward sustainability, the British group SustainAbility points out that information technology is the sector to watch given its ability to dematerialize. While acknowledging the environmental problems including landscapes covered with towers for communication networks, the sector's prospects in a sustainable world are excellent, the group concludes.[45] However, business, government, and environmental groups are still at a very early stage of developing a language to talk about and measures to weigh the positive contributions of the computer and electronics sector at a mid-level between broad trends and generalizations and specific examples. benefits.

### *3.4 Limited participation in environmental policymaking*

The computer and electronics sector is most readily identified with lead firms such as Intel and Microsoft and trade and professional groups such as the American Electronics Association and IEEE. In developing environmental policies, however, there are many other players: all types of firms, employees; suppliers and customers; government officials working on environmental issues at the local, state, national, and international levels; communities that host electronics facilities; and civic, justice, and environmental groups. Participation in environmental policymaking is still limited to relatively few of these players.

Electronics firms have different interests in environmental policy depending on their products, place in the product chain, size, their history, and the nature of their environmental problems. As the members of sub-sectors producing the most waste and emissions, semiconductor, printed wiring board, and cathode ray tube companies have worked most closely with EPA both on compliance issues and initiatives such as design for the environment. The Electronic Industries Alliance serves as a primary representative of companies on environmental regulatory and legislative issues in Washington, D.C.

Some electronics firms grew out of a close relationship with the defense industry. Others are emerging from decades of telecommunications regulation or moving from photographic film to digital imagery. These firms tend to have long-term experience on environmental policy issues at the national level as do some of the older computer companies. Until quite recently, Silicon Valley firms encountered government at the state and local levels. The national government has been remote despite its role in nurturing much of the technology including the Internet. In 1994, Jerry Kaplan noted: "It was as though we lived in the Wild West, where it was difficult for authorities to enforce the law because of the distances and the lack of a local presence. Today the problem is different, but the result is the same: the government doesn't understand the territory, and the technology moves faster than the authorities can act." [46] Large companies like the network equipment company Cisco are just opening Washington offices in 1998, and environment is not on their primary agenda. Few companies that support and use electronic networking or make software are active on environmental issues. Nor is environment on the agenda of the high-tech leaders who have formed a Technology Network, Its mission is to apply the principles of flexibility, decentralization, and innovation, that are remaking the business world, to education, government, and almost any of the nation's pressing social problems.[47] Much of the computer and electronics sector champions market-driven self-regulation as a basic tenet in all areas, including the environment.[48]

Worker participation in the environmental policymaking process for the sector is limited. Only a small portion of electronics workers belong to unions. The exceptions are workers at some of the older telecommunications companies organized by the Communications Workers of America. The more narrowly defined electronics and computer industry is almost entirely unorganized. Silicon Valley companies have sought to avoid what they see as the significant disadvantages of labor relations in the vertically integrated and hierarchically run companies of the East Coast. Some worker and health groups do focus on the electronics industry, however. The Santa Clara Center for Occupational Safety and Health is one example of a group that serves workers in the industry and tries to improve the availability of data.

A few community groups have developed considerable expertise on the sector as environmental issues have emerged near their homes. The Silicon Valley Toxics Coalition was established in the early 1980s as electronics facilities were found to be the sources of contaminated groundwater. It has joined with groups located in communities with electronics plants to address implications for local residents and people of color and native Americans through a Campaign for Responsible Technology and a Southwest Network for Environmental and Economic Justice. The campaign has issued a statement of Silicon Principles calling for toxics use reduction, health and safety education and monitoring, good neighbor agreements, civilian research and development, application of corporate policies to subcontractors and suppliers and internationally, a life cycle approach, and community oversight.[49] Recently the Coalition has begun tracking the environmental information made public by companies.

A review of public reports and statements related to sustainable development by electronics companies found that firms “are far more likely to identify trade associations, academics, and principal customers and suppliers as a ‘first tier’ set of stakeholders. They are unlikely to make explicit policy commitments to a broader group of stakeholders.”[50]

Perhaps the most notable largely missing participants in environmental policymaking for the sector are the purchasers and users of the technology. The roles which they might play are illustrated by the Consumers Union and the Loka Institute. The Consumers Union has begun to include some environmental issues such as energy efficiency in its reporting on electronic products.[51] The Loka Institute is a non-profit group dedicated to making science and technology responsive to democratically decided social and environmental concerns. Drawing on experience in Denmark, it convened a citizens' panel on Telecommunications and the Future of Democracy in April 1997 that demonstrates one model for broader involvement. While it did not address environmental issues, it provided a model for informed citizen input to technology development.[52]

From a broad view of the sector's focus on technology, economic niche, environmental problems and opportunities, and actors in the sector, the WRI project turned its focus on a specific product chain to gain a clearer understanding of the drivers and barriers that a changing environmental policy needs to take into account.

## 4. Incorporating the Environmental Factor: A Case Study of the Disk Drive Product Chain

Developing policies to encourage adoption of environmental technologies requires a better understanding of current practices in the electronics sector. To gain this understanding, the World Resources Institute commissioned a case study to examine the practice of design for environment within and among companies along a sample product chain in one segment of the sector. The following discussion is drawn from the case study prepared by Robert L. Ferrone with the assistance of David Galbraith.[53] The case study was framed and reviewed by the WRI Electronics Working Group.

Disk drives were chosen as the focus of the case study for four reasons:

1) Disk drives are made from a wide variety of materials including metals, composites, polymers, and solvents. They present opportunities to avoid or reduce environmental impacts at all stages from manufacture through use, recycling, and waste management that have so far received less attention than segments of the sector such as semiconductors.

2) Information storage is a rapidly growing and key component of electronics equipment. As competition intensifies and the disk drive industry comes under increasing cost pressure, the timing may be right for disk drive companies to use improved environmental performance as an

opportunity to gain a competitive edge by, for instance, reusing old parts or rethinking choices of materials.

3) Disk drive technologies are changing rapidly and have short life cycles of six months to one year from design to volume manufacturing. Decision points may therefore be easier to identify and track.

4) The disk drive product stream illustrates important characteristics of the electronics sector as a whole: short product cycles; international scope; and products built from components (such as printed wiring boards ) along a horizontal supply chain.

### *4.1 Disk drive technology*

Disk drives store information for computers and other electronic equipment. They are composed of disks (storage media), heads (reading and writing components), and printed wiring boards (interface circuitry). (Figure 1). Disk drives read and write information by using heads mounted at the end of an arm that swings over the surface of a rotating disk, much like phonograph needles on a record. The disk is made of aluminum with a magnetic coating. The drive has two motors. The spin motor rotates the disk. The actuator motor moves the head across the surface of the disk to the desired position. The head is an electromagnet. Its polarity changes whenever the drive direction of the electrical current passing through the head changes.

This case study addresses only "hard" disk drives that use magnetic technology. Hard drives may be housed inside the computer or other equipment. They may also be external to it with their own plastic covers, connecting cables, and often a separate power supply unit. Hard drives differ from drives built to handle removable floppy disks and CD-ROMs. The study covers only drives that use magnetic technology to read and write information, the most common type now in use. It does not cover drives that read and write with optical or chemistry-based technology.

### *4.2 Growth of the disk drive industry*

The 40-year history of disk drives is one of extraordinary innovation and competition. Researchers at IBM developed the first disk drive in 1956. It had 50 24-inch disks and could store

5 megabytes of information. (One byte equals one numeric character; one megabyte equals one million bytes.) Competition has focused on increasing storage capacity, decreasing disk size, and increasing access speed. Engineers increased the density of disks at the rate of about 35% a year for 20 years even as they reduced the disk to the size of the palm of a hand.

Independent disk drive firms emerged in the late 1960s. The 100 or so disk drive companies operating in the late 1980s had been reduced to about 50 by the early 1990s. As of 1997, seven firms dominated the competition for the growing market: Fujitsu, IBM, Mazler, Quantum, Seagate, Toshiba, and Western Digital. Although the market was growing at 15 to 20 percent a year, further consolidation of the industry was expected.[54] Disk/Trends estimated expected revenues in 1997 at $34 billion with revenues expected to more than double by 2000 as the computer industry and sophisticated software markets continue to grow. Total disk drives shipped are expected to go from 105 million in 1996 to over 200 million in 2000.

### *4.3 Environmental issues in the disk drive chain*

Disk drives meet the environment through use of hazardous materials and energy and generation of waste and pollution at all stages of the product stream from obtaining materials and manufacture of components through assembly, use, and disposal of products.

*Energy use*. At the manufacturing stage, both plating and coating the disk and making the heads are energy-intensive processes. The aluminum used in the clam shell that encloses the drive requires high energy use upstream as it is refined. Unlike the computer as a whole, energy use during a disk drive's working life is lower than that required obtain and refine the material later used in manufacture.

*Hazardous materials*. Metallic compounds used in making disk drives include beryllium-copper, nickel-cobalt, and lead. Nickel is used in the disk itself while printed wiring boards and semiconductors used in the drive contain copper and lead. Some of these materials remain in the product and others become waste. The data on environmental impacts of obtaining these materials is not easily available to companies at the design stage.

*Wastewater*. Large quantities of water are used in cleaning components such as the semiconductor chips in the head circuitry and circuit board in the drive. The water is usually used in one manufacturing process and then released as wastewater.

*Solid waste*. A typical yield in manufacturing disk drives is 70 percent. This means that about 70 percent of the material used in production ends up in the product sold to customers. The remaining 30 percent is usually discarded as waste. Manufacturers are just beginning to think about designing the disk drives themselves for recycling and reuse given its relatively small size and value.

### *4.4 Interviews with companies along a disk drive product chain*

To explore the practice of incorporating environmental issues into product design, environmental and product development managers were interviewed in companies at three stages in the disk drive product stream: makers of components such as electronic circuitry (Motorola) and connectors (AMP) used in disk drives; a manufacturer of disk drives (Quantum); and manufacturer of computers (Dell).[55] (Figure 2)

*Motorola, Inc*. Motorola is a leading provider of semiconductors and advanced electronic systems, with annual sales of $28 billion in 1996. It manufactures several components of disk drives, including the interface circuitry. Its headquarters are in Chicago, Illinois, with plants in Europe, Asia, and North America.

*AMP Incorporated*. AMP develops and manufactures a wide variety of electronic/electrical interconnection devices. It is the world's largest producer of interconnection devices with 1995 sales of over $5 billion. It supplies cables and connectors that link external disk drives to the main computer system. Headquarters are in Harrisburg, Pennsylvania, with plants in Europe, Asia, and North America.

*Quantum Corporation*. Quantum is a leading manufacturer of hard disk drives worldwide with sales of $4.4 billion in 1996. It supplies drives for desktop computers, servers, and networked databases. It assembles the drives from parts and components it has bought or manufactured. Headquartered in Milpitas, California, it has manufacturing plants in California, Colorado, and

Massachusetts. Its Japanese manufacturing partner is Matsushita-Kotobuki Electronics Industries Ltd. with plants in Japan, Ireland, Malaysia, and Singapore.

*Dell Computer Corporation*. Dell is one of the world's largest personal computer companies with $5 billion in sales in 1995-6. Dell purchases disk drives for use in its computers which it distributes directly to customers. Its headquarters are in Austin, Texas; manufacturing plants are located in Texas, Ireland, and Malaysia.

Working with the consultant and the Electronics Working Group, the World Resources Institute prepared a list of questions to guide the interviews. These focused on company structure and practices in incorporating environmental issues into design and the present and potential influence of a range of policies Ferrone and Galbraith conducted interviews with environmental and design staff at the four companies in 1996 and 1997. (See Appendix D)

### *4.5 Findings of interviews*

The interviews found that as of the mid-1990s participating companies were in the early stages of introducing design for environment into their companies through measures such as providing training. The major driver for environmental action remained compliance with regulations. Some conversations indicated that a more strategic approach, built on customer demand and business opportunity as well as anticipating future regulations, might be emerging.

#### 4.5.1 Early steps in product design for the environment

Individual companies along the chain have taken some important steps in designing products for the environment. Dell has redesigned the chassis of its computers to use more uniform materials and to ensure faster disassembly and recycling. AMP adopted an engineering specification requiring material identification on new plastic parts. This allows easier recycling of connectors and reduces solid waste.

AMP, Dell, and Motorola have all established courses on design for environment. AMP's course is one result of a senior management commitment to this practice. The company has initiated a mandatory course that focuses on the importance of environmental performance for customers and the company's bottom line and ability to compete. The eight-hour course introduces participants to emerging tools, particularly life-cycle analysis. Developed by the company's Technology, Environmental, and Global Engineering Groups with the University of Wisconsin, the course is disseminated using a "train the trainers" approach. To increase the program's visibility and determine its effectiveness, AMP runs an internal competition on designs that, for example, reduce water use and the amount of solid waste. (Figures 3 and 4)

### 4.5.2 Internal structure and information flow

The primary and sometimes sole *responsibility of the environmental department is* generally *to ensure compliance*. The interaction between environmental managers and the design team is usually limited to communicating relevant environmental regulations and ensuring compliance with them. Quantum, for example, has an environment department of two people. They inform design managers about the specifications needed to meet environmental laws. However, the environment department is now structured to respond to rather than anticipate changing policies such as those that may affect the cost and use of major raw materials for disk drives such as aluminum.

AMP's environmental department has a somewhat broader mandate. Besides ensuring compliance, it meets customer environmental demands and reduces AMP's impact on the environment by managing resources responsibly. At Motorola, individual staff take the initiative to evaluate product design for material and energy efficiency. These actions, however, are not part of an official function.

*Reviewing product designs for business opportunities through superior environmental performance is the exception rather than a primary function of the design team*. Design teams examine environmental impacts mainly to ensure that products will meet the regulations communicated by the environmental department. AMP's design team also is charged with reviewing the environmental implications of designs. The quick turn-around time required by customers influences the extent of the review. At Quantum, some ability to disassemble the drive is built into design so that malfunctioning drives can be slightly reworked. However, detailed information was not available about the financial and technical aspects of recycling disk drives that would provide the basis for deciding whether to design for disassembly.

*Design teams lack the analytical tools and information needed to analyze environmental impacts and costs*. As the Quantum example indicates, the team does not have the sophisticated analytical tools needed to examine environmental issues. Addressing reuse and recyclability provides a particular challenge for the disk drive product chain because the parts are small and inexpensive. At $10 for the head, $10 for the disk, and $30 for all other components, a disk drive costs about $50. Some components become obsolete; others, such as the ball bearings, may wear out during a first use. However, a detailed analysis on materials choice, risk reduction, and cost from a life cycle view has not yet been carried out.

Dell uses some rudimentary tools to calculate and analyze the cost of material and energy inputs, and Motorola made preliminary efforts to assess opportunities to decrease costs by performing environmental cost accounting at several assembly and operations plants. Motorola did not find the information valuable enough to justify continued collection. One barrier is getting a level of information about environmental characteristics of materials that is useful. Most information has been either too general or too detailed for use in design decisions. In addition, companies that have made many gains in the efficiency of manufacturing products (as Motorola did in its quality programs) find that future gains lie in making products that perform functions in ways that use materials and energy more efficiently or that avoid risk. These changes usually also require changes at the systems level that are more difficult for a single company to influence.

*Interaction between marketing departments and design teams on environmental performance remains limited*. An indication that designers are approaching environment as a business opportunity would be close communication with the marketing team. Environmental staff noted that marketing managers were beginning to relay questions from customers on the environment, a first step in improved communication.

### 4.5.3 Communication among companies along the chain

Companies along the disk drive chain are beginning to communicate with suppliers about environmental regulations and material restrictions through fact sheets or questionnaires. Quantum is developing a questionnaire on manufacturing processes for the company's suppliers to complete. It is aimed at learning the chemicals suppliers use in manufacturing and cleaning disk drive components. Its own customers further along the chain are beginning to ask for this information, especially as producer responsibility programs grow in Europe.

Company managers note that commercial customer demand could drive attention to improving the environmental attributes of products. Within the chain, a manager at a component maker says that disk drive and computer manufacturers further along the chain do not bring component makers into the longer-range planning process for new products. In addition, each customer has a different environmental priority. Some care about energy efficiency and others about substitution of a particular material. So far, no companies in the chain find that customers rate improved environmental performance as high as technical performance and reliability. A general assumption is that only five percent of the market buys based on the environmental factor. However, another manager noted that changing practices in Europe might lead to a rethinking of his company's approach in the near future.

### 4.5.4 Summary findings of interviews

This study of a disk drive product stream indicates that much potential opportunities to integrate environmental factors into product design in the electronics sector as a strategic approach remains to be realized. Barriers to these opportunities are at both the leadership and technical level.

- The primary or sole responsibility of the environmental department is generally to ensure compliance.

- Reviewing a design for business opportunities through superior environmental performance is not a primary function of the design team.

- Within companies, communication between the two departments and with marketing on environmental performance is quite limited.

- Unit cost of production, time to market, product performance and reliability, and compliance with environmental regulations are the variables of concern to designers. Some environmental opportunities are now identified that may save money but not enough compared to other investment opportunities or to make it worthwhile to address the difficulties of making the changes. The short life cycle and complex nature of products and processes mean that any change may slow the cycle--adding to costs or missing the market. Design teams need tools that provide the right level of detail to analyze costs of environmental impacts and do not add to the time needed to design the product.

- Customers and suppliers generally communicate by the customer's providing technical specifications and relevant environmental regulations to the supplier.

Stronger departmental mandates, improved communication within companies and along the chain, and better tools are most likely to result from stronger public and business leadership on priorities for environmental improvement; increased leadership from business unit and financial managers within companies; and growing customer demand for "green" products both along the product chain and in society.

### *4.6 Taking a more strategic approach to environmental product design in companies*

Companies now invest to improve product "functionality", reliability, unit cost of production, and time to market. Environmental compliance is viewed as a cost. The fundamental step in moving to a strategic approach to environmental product design is viewing the environmental factor as a focus for investment. Doing this requires a commitment by senior management to go beyond compliance and see the environment as a business opportunity. To implement this approach requires putting in place a system that

- provides for an appropriate level of environmental analysis at each phase of the design process;

- places business and financial managers in the lead of design teams to ensure that analysis is considered and trade-offs are made.

Product design is the key decision point because, as noted earlier, as much as 80% of the costs of making the product and of its potential for environmental impacts are determined by decisions at this stage. The opportunity for improving environmental performance is greatest as the product is selected and designed and decreases with each stage of the product's life cycle. The cost increases at each stage, reaching the highest level with remediation. (Figure 5) Incorporating the environmental factor into the design processes requires a detailed understanding of the design decision process. The disk drive design process goes through four phases in six months. (Figure 6)

- The concept starts at design phase 0 with the definition of the product requirements. Product strategy development continues with a feasibility study, consideration of new alternatives, preliminary engineering plans and functional specifications. While manufacturing, customer service, and sales impacts and requirements are factored into the phase 0 business plan, environmental impacts and requirements are now not usually considered. A strategic approach would start at this stage. (Figure 7)

- Baseline design review occurs in design phase 1. As designers determine the functional specifications for the product, they make choices that determine the environmental impacts of the product. They select the materials and determine how the product will be manufactured and packaged. It is at this phase that some companies are beginning to consider how a product will be reused or recycled. (Figure 8)

- Design phase 2 is the design readiness review. Vendors are chosen as the design is completed. At the end of this phase materials are ordered. If changes in materials need to be made at this point or in phase 3--manufacturing readiness, they are likely to be costly in time and lost revenue because the inventory of materials is already set. (Figure 9)

A company needs a detailed manual of the environmental analysis that the design team will perform at each phase. Some companies have begun to develop approaches to analysis. William Hoffman at Motorola's Corporate Manufacturing Research Center, for example, describes a three-tiered approach to each product stage. (Figure 10) The first tier is a simple matrix of possible impacts on resource use, energy use, human toxicity and eco-toxicity at each stage of a life cycle starting with choosing parts and moving through manufacturing, transport, product use, and managing the product at the end of life. (Figure 11) The second tier analyzes individual parts, while the third allows for a life cycle assessment of the entire product as the prototype is completed.[56] From the designer's view, life cycle decisionmaking is a complex series of analyses and trade-offs. (Figure 12)

In order to move to a more strategic, business-led approach make decisions based on an environmental analysis, Ferrone suggests enhancing management of the process of introducing new products. The current and enhanced processes are compared in Box 1. The key improvements include the following:

- Improved communication on environmental factors across departments and increased demand by customers for environmental performance would be incorporated as the marketing department identifies a new or expanded product function.

- Engineering and marketing departments would continue to specify the function. As these departments carry out the feasibility study and build product prototypes, however, a new element would be introduced. The feasibility study would include review of the environmental issues for the product's entire life cycle. It would address environmental aspects of material choices and ways of closing the product cycle through reuse of the product or recycling of components or materials.

- The design department now usually leads a team including design, marketing, manufacturing, purchasing, and service in designing the product. The enhanced process would add the business and finance managers. The business manager would drive the team as it prepares an integrated plan to achieve product requirements. In a team driven by design, the ability to assess the kinds of tradeoffs and make changes that may be required in taking account of environmental factors is limited. A team led by the business manager could better make those decisions. Including the finance manager would similarly allow considering total life cycle cost tradeoffs. It would allow environmental factors to be treated as investments to take advantage of a business opportunity such as being the first to use an environmentally preferable material or to design a product that allows significantly easier recycling--for example, by dramatically reducing the number of materials.

- The team would continue to function beyond the new product development phase. Rather, it would continue through the use and recycle/reuse/waste management stages. Manufacturing members would learn ways to improve the product from examining returned products. Opportunities for cost savings through reuse of parts would be explored.

While company leadership and commercial customer demand are likely have spurred some firms to move toward a strategic approach to product design, as of 1997 companies in this chain were still at a relatively early stage.

### *4.7 Policies to shift companies toward a strategic approach to product design*

In the interviews and in discussion of this case study in the Electronics Working Group, two policy instruments--take-back and product performance standards modeled on the Energy Star approach--were by far the most frequently mentioned as likely to be influential in spurring companies toward a more strategic approach to product design. Although the WRI Electronics Working Group did not attempt to reach agreement on policy recommendations, the take-back policies developing in Europe and the Energy Star standards for electronic equipment dominated the discussion as the most relevant policy approaches to stimulate environmental product design. Case study author Ferrone urged education of top managers and further development of tools for designers as appropriate roles for government. These policies are further discussed in Section 6 of this report.

Box 1 : **Moving to a Business-Led Process to Introduce New Products**

| ***Today's Process*** | ***Enhanced Process*** |
|---|---|
| Customer or marketing initiate by request for new or expanded product function | Same |
| Function specified by engineering and marketing | Same |

| | |
|---|---|
| Engineering and marketing prepare feasibility study, including prototypes | Feasibility study includes review of design and material aspects of entire product life cycle, i.e. reusability and recyclability |
| Team led by design and includes marketing, manufacturing, purchasing, service | Business manager leads team. Finance participates. |
| Team prepares integrated plan to achieve product requirements | Same |
| *Design*: specifies design, prepares product prototype, design qualification<br><br>*Manufacturing*: assesses material and process needs, modifies or creates new processes; vendor qualification, acquires material, builds initial units, develops resource and training needs, manufacturing qualification | *Business* manager drives team to achieve product requirements and goals, leads team in assessing tradeoffs and changes in plan<br><br>*Finance*: projects total life cycle cost of product, monitors costs of new product plan<br><br>Other member's responsibilities remain the same |
| *Service*: project serviceability/ warranty costs, train field staff | |
| *Marketing*: develop and implement product launch plan including customer test sites | |
| Monitor progress of start up to plan | Same |
| Ship product in volume | Same |
| Team disbanded | Team monitors progress of product toward goals through entire life cycle. Business manager continues to lead team although other members of team may change. |

## 5. The Project as Incubator for Sector Policy Approaches

Besides exploring the state of design for environment practices along a product chain, the WRI project on policy frameworks for stimulating environmental technology in the computer and electronics sector served as the incubator for work on two other approaches to sector policy. Both approaches developed as an outcome of discussions of the WRI Electronics Working Group. The first looked at the business opportunity for sector companies in going beyond "developing more gadgets," in the words of one participant, to building a sustainable world. The result was handing off a project to the WRI Climate Protection Initiative that surveyed the state of electronics innovation for climate protection. The second approach was aimed at getting a handle on the global structure of the sector by examining the financial and material flows it engenders and their implications for the environment.

### *5.1 Electronics Innovation for Climate Protection*

One element in Stuart Hart's proposed four-part sustainability portfolio is the sustainability vision. It asks the questions: "Does our corporate vision direct us toward the solution of social and environmental problems? Does our vision guide the development of new technologies, markets, products, and processes?" It complements the other external element--product stewardship, which design for environment addresses.[57] The WRI Electronics Working Group discussed how policies might encourage companies to focus product development in ways that help society move toward sustainability. Could policies encourage companies to see environmental issues as an opportunity to develop products and provide services that increase revenues rather than add costs? The Wirthlin poll noted earlier found that nearly a quarter of the respondents thought that the electronics sector could help solve environmental problems--more than for any other sector.

After these discussions, the project investigators found that the WRI Climate Protection Initiative (an Institute-wide initiative to promote action on climate protection in the business community) was interested in pursuing analysis of how innovation in the electronics sector might help reduce greenhouse gases. The two WRI programs worked together to commission a scoping paper to examine the role of electronics technology in climate protection and how companies viewed the opportunities. John Horrigan, who recently had completed his doctorate focused on technology policy, prepared a scoping paper on "Information Technology and Climate Protection: Opportunities and Challenges" under a consulting agreement.

The scoping paper teased out the relationship between three types of electronics technology--sensors, bandwidth, and controls-- and the reduction of greenhouse gas emissions. Sensors are used to optimize the use of energy in motors in cars, trucks, and planes and industrial processes as well as in lighting and heating and cooling systems in homes and offices. Sensors turn on the light as a person enters a room and turn it off as she leaves. Displays and bandwidth combine to enable electronic communication to replace some energy-intensive travel. More portable and higher quality displays are likely to increase use of videoconferencing. Visual and data communication require much more bandwidth than voice communication. Thus companies that make more bandwidth available whether through wires, wireless, switches or software all contribute to an increase in network communication that can replace some travel and transport of information. As the cost of these technologies drops, their potential to reduce greenhouse gases grows as customers are more likely to purchase more efficient equipment and engage in electronic communication. The paper also described how growing public demand and developing policies to protect the climate might combine to increase demand for these products.

After discussions of the scoping paper at February and June 1997 meetings of the WRI Electronics Working Group, the project became part of the Climate Protection Initiative which then shared the scoping with several sets of reviewers. The International Cooperative for Environmental Leadership (ICEL) convened one group. This consortium of companies and associates that took the lead on phasing out chlorofluorocarbons made a commitment to promoting climate-protective technologies in September 1997. Its members suggested including specific examples of the applications of the technologies in the paper. The Electronic Industries Alliance (EIA), a trade group of about 2000 companies, also circulated the paper to members active in the EIA Environmental Issues Council. Member companies of ICEL and EIA provided examples of products that use electronics technology to help reduce greenhouse gases. The examples include both improvements in existing products--mainly improvement in energy efficiency--and development of products that allow activities to be performed in new ways. The second category is largely products that enable faster, higher quality electronic communication.

The report on this effort was published as *Taking a Byte Out of Carbon: Electronics Innovation for Climate Protection* in July 1998.[58] Issued jointly with ICEL and EIA, the report outlines how policies such as procurement and labeling under the Energy Star Program and the development of the Kyoto Protocol are likely to increase the market for climate-protective technologies exemplified by those described in the report. It notes business support for policy incentives for purchasing energy-efficient products and partnerships for research and development into innovative technology. It recommends that companies prepare a roadmap to lay out the scale and nature of the opportunity for electronic products that can help address climate change. A roadmap might focus on applications of electronics technology in heating, cooling and lighting offices and homes more efficiently; in substituting networking for physical transport; in improving efficiency of transport; and in increasing efficiency of energy and materials use in industry. It could also address barriers such as the need for methods to measure the net climate benefits of electronic communication.

The project on electronics innovation for climate protection illustrated some of the possibilities and challenges in the "opportunities approach."

- Untangling the threads through which electronics technology can help solve an environmental problem--in this case reducing greenhouse gases--is a necessary first step in defining technology's potential contribution. The report starts to provide a language--the specific examples and arresting facts--for talking about the relationship of electronics technology and a framework for analyzing it. For example, the Electronic Industries Alliance drew on the report in issuing its Statement of Principles on Global Climate Change in March 1998.

- Quantitative data are available on energy efficiency of office equipment and building management through Energy Star programs. In contrast, little analysis has apparently been done of the more difficult to measure net benefits of electronic communication. A few companies are developing data on savings from using particular products. For example, Kodak has calculated the reduction in greenhouse gases offered by using its digital camera to meet by video rather than flying to a face-to-face session. Meeting by video rather than flying 600 miles has just one percent of the global warming potential.[59]

- Climate protection policies may provide incentives for companies to seek business opportunities in providing products that reduce greenhouse gases. A few companies such as Mitsubishi, Nortel, and United Technologies Corporation acknowledge emerging climate policies such as the Kyoto Protocol as part of the picture that influences development of products. Nortel says: its technology will “continue to bring people together--virtually--while decreasing climate change impacts associated with transportation.”

- Reports that focus on business solutions for one environmental problem may be viewed as “hype” or “greenwashing”, especially when quantitative data are limited and the sector is a source of other environmental problems not addressed in the same report. This concern may be partly addressed by improving measurement methods and developing a roadmap that lays out specific steps.

### *5.2 Tracking sector material flows across national boundaries*

The computer and electronics sector operates globally. Business decisions of what to make, where to make it, and with whom to partner or outsource are driven by factors such as availability of material, availability of skilled labor, manufacturing costs, distribution networks, and market access. The firm that designs the product is likely to be located in one country while manufacturing and sourcing of raw materials take place half-way around the globe. For instance, Malaysia and Thailand are lead makers of disk drives for U.S. firms that design and sell electronic products. Japan gets silicon from Brazil. Understanding the environmental impact of the sector requires understanding the impact of each phase of the product stream..

One way to get a sense of the scale and geographic range of the sector’s global structure and its environmental implications would be to track the material and product flows in the sector. These data could first provide a better basic understanding of volume and type of materials mobilized by this sector--the leader in dematerialization but also an important user of toxic materials. They could also provide some understanding of the locations in which environmental issues might arise.

The project took a first cut at trying to track flows in several subsectors. Resources did not allow going further with this piece of the project. However, WRI is engaged in developing indicators of material flows and expects to carry out work at the sector level, possibly including electronics. Learnings included the following.

- Both traditional environmental consultants and company environmental staff are likely to start from the regulatory and end-of-pipe control perspective that underlies current environmental regulation. Future work would benefit from using an industrial ecology framework in understanding the relationship of the sector's global structure to the environment. Industrial ecology provides the conceptual tools to analyze the flows of materials and energy through the economy. This approach would estimate the volume, velocity (length of time a material remains in the economy), mobility (extent material is likely to move once it enters the environment), and the quality (toxicity, persistence) of materials flowing through the sector.

- Data most easily available are for wastes from the sub-sectors of semiconductors and printed wiring boards plants in the United States because these are sectors and materials now regulated by EPA. Little attention has been paid to tracking sources of materials upstream. The U.S. Industrial Outlook, prepared by the Department of Commerce, tracks the value of production and value of the market of electronic components in different countries.[60] A few companies, such as IBM, are beginning to track their wastes and releases in a standardized way at all their sites around the world. [61] The aggregated data used in a sector materials flow study based on an industrial ecology framework are likely to be more available and less sensitive than facility level data.

## 6. Sector Policy Frameworks

What would an environmental policy framework to stimulate environmental technology in the computer and electronics sector look like? This section addresses that question in two ways. It first describes the views put forth at a session on the "ecotransformation" of the electronics sector at a meeting of the Greening of Industry Network. The it turns to the policy perspective and outlines the key elements of a framework to stimulate environmental technology in the computer and electronics sector.

### *6.1 Ecotransformation of the electronics sector: A view as the century ends*

At the 1997 International Conference of the Greening of Industry Network in Santa Barbara, California, participants from business, government, and non-governmental organizations from around the world examined potential pathways to ecotransformation in six sectors of the economy. One was the electronics sector.[62] After presentations on electronic asset management in the U.S. Postal Service, diffusion of design for environment, and a resource-based perspective on environmental strategy for the sector,[63] the group brainstormed a list of the drivers for transforming companies in the sector and the barriers to transformation. These are listed (but not ranked) in Box 2.

Participants saw leadership as the crucial internal driver for change within companies. They also stressed the importance of the competitive edge that a strategy based on ecotransformation can provide through better information on use of products and more efficient use of materials. They identified the emerging "take back" regulations in Europe as a primary driver for change from outside companies and stressed the potential power of pressure from customers for "green" products. Many of the barriers stem from the lack of knowledge about sustainability issues within companies and among customers and from missing policies and tools to apply environmental goals in the sector. More fundamental, however, is the sector's single-minded focus on delivering new technology that rapidly becomes obsolescent products. The pace means environmental benefits are seldom part of the calculus or are rapidly traded off for time to market and more powerful products. While new products are often more efficient and also offer less resource-intensive ways to live, work, and travel, those gains may be offset by increasing production and activity. Far-flung supply chains and markets mean high demand for transport by the sector itself with its related environmental consequences.

Many members of the group concluded that the longer-term vision of ecotransformation is to redefine the sector as delivering value rather than specific products. The questions then become: How does electronics technology create value for customers and society? What

Box 2 **Ecotransformation of the Electronics Sector: Drivers and Barriers**

**Drivers**

- internal company leadership
- rapidly changing technologies that often use material and energy more efficiently
- rapidly changing organization
- competition for global markets
- pressure points along the global supply chain
- corporate customer demand
- costs of resources and liability
- regulations, particularly emerging “take back” policies

**Barriers**

- short attention span for issues peripheral to technology development
- rapid obsolescence of products, production equipment, and people
- environmental issues not addressed at a strategic level
- little awareness of sustainability issues in companies or among customers
- a primary focus in companies on reducing costs
- weak internal relationships between environmental and product development groups
- multiple suppliers of components along supply chain
- lack of strong customer relationships
- large energy demands for transport in global supply and distribution chains
- lack of clear public environmental goals
- lack of market pull with little awareness of sustainability issues among customers
- missing players in debate--software, transport, services, consumers
- efficiency gains may be offset by growth in production

activities or services will companies offer? Xerox provides one model in its focus on providing documents and its practice of leasing equipment rather than selling a particular product such as a copier. In the shorter-term, participants urged establishing clear goals, involving missing players, and determining the steps needed to move toward a value and activity-based approach. At least one participant questioned the need for such a fundamental change and, in any case, emphasized the importance of an incremental process. Another participant suggested that a segmented approach led by companies that choose to be early adopters of change is one way forward.

### *6.2. A sector policy framework to stimulate environmental technology in the computer and electronics sector*

A sector approach to environmental policy, as discussed in section 2, provides an opportunity to identify the sources of environmental impacts in sector decisions, takes a systems approach, and develops policies with sector decisionmakers that can be effectively implemented. Following this approach, policies to stimulate environmental technology in the computer and electronics sector would focus on decisions in new product development, the product system, and ways to involve more of the key decisionmakers in the policymaking process.

- *The source*. At the root of both the sector's environmental impact is its attention to getting new products to the market faster and at less cost. Therefore, it is product development decisions by investment analysts, business managers, marketers, and design engineers and those of their customers and suppliers that environmental policies need to influence. The policy framework would aim to incorporate the environmental factor along with function and cost factors in both long-term development of technology and at the more detailed design stage. In fact, the sector's focus on new product development is also clearly an environmental opportunity.

- *The system.* The system of the computer and electronics sector is the product stream. The production facility that is now the focus of most environmental policy is one--often environmentally important--phase along this chain. The challenge for policy is to link the sector's business product system to its impacts on the environment. Policy needs to drive connections between the business product cycle that develops and delivers the new product and the physical product cycle which extends upstream and downstream.

· *The process*. The sector approach's strength in identifying key decisionmakers and involving them in developing and negotiating policy is also a significant challenge in the computer and electronics sector. Sector participants are just beginning to gain experience with policy development and implementation beyond applying traditional regulation to pollution-intensive facilities in a few sub-sectors. Energy Star product standards demonstrate the policy possibilities with a policy that influences one slice of design. The EPR2 Roundtable includes changes in design in its discussions on end-of-life management of electronic products. The Common Sense Initiative highlights the differing visions and styles among sector stakeholders. To the extent that they are organized, constituencies such as workers, communities, and consumers have limited resources. Supplier and customer relations are among the most sensitive issues for companies to address, and addressing product issues is new for many in government agencies. Nevertheless, broad directions for policies to stimulate environmental technology are emerging from sector debate.

The likely elements of a policy framework that focuses on product development decisions and links the business and physical product chains include:

- environmental goals;
- public metrics and certification systems;
- tools to apply design for environment and leverage the supply chain;
- tools to stimulate market demand;
- research;
- much broader public awareness and engagement in both the environmental opportunities and problems posed by the computer and electronics sector.

In 1996, the U.S. President's Council on Sustainable Development took an important step in recognizing the need for a framework on extended product responsibility. The Council recommended a shared and voluntary approach. Participants in policymaking for the computer and electronics sector in the United States remain divided about how to move forward on the key issue:

*How* to share environmental responsibility and communicate environmental information along the product chain. Many companies advocate self-regulation. They want to develop their own methods of addressing environmental issues upstream and downstream and apply their own tools such as performance standards and roadmaps to environmental issues. In contrast, environmental groups urge standardized, public reporting and toxics use reduction. Developing a new framework will require changes in both approaches. It will require learning among the investors, marketers, product engineers, and intellectual property lawyers on the technology front and among the citizens and the experts--from environmental lawyers, engineers, economists, ecologists, to toxicologists--now engaged in environmental policymaking.[64] It will also mean involving other perspectives not now represented. Two examples are software companies and consumer groups.

This learning has started. It draws on the sector's tools in managing the product development process as well as experience in some environmental policy arenas. One beginning learning is that the sector's tools--performance standards, roadmaps, design for "x" all focus on *future* technology. In that, significantly, they differ from pollution control policy that identifies the current sources of emissions that pose a risk to health or the environment and sets limits, usually drawn from the best available current technology. They also differ from the current approach to end-of-life management of electronic products which tends to focus on collection and recycling with less attention to changes in product design or more dramatic changes in technology. Environmental policymakers bring experience working with the sector in phasing out chlorofluorocarbons under the Montreal Protocol and setting product energy use standards. Ironically, one major contribution of environmental groups to policy development for electronic products may be the use of information technology to allow the public to compare the environmental performance of companies. So far, reporting under the Toxics Release Inventory, the major example of standardized, public reporting, applies only to production processes. It does not include the data needed to track the development toward environmental technology. State programs in Massachusetts and New Jersey both require pollution prevention planning and collect data that allows some tracking of amounts of some toxic chemicals. The following discussion notes experience so far under each of the proposed framework elements and suggests promising directions.

### 6.2.1 Setting environmental goals

When environmental goals are clear and widely-agreed internationally and nationally, action follows. "Without question, the main force motivating producers and users to invest in alternatives was the international community's decision to control CFCs and halons through the Montreal Protocol and the eventual adoption of the phase-out goal itself," concludes an analysis of the U.S. experience with ozone protection policy.[65] Similarly, programs to encourage energy efficiency in products have a record of success. In this case, the standards have been agreed at levels that a large portion of companies think they can achieve. In addition, these energy standards are relatively easy to implement and measure.

To turn the electronics product stream into one that is "greener", both in its own relations to the environment and in helping solve major environmental problems such as climate change, means establishing further environmental goals. Who sets the goals, at what level, and in what form will vary with the issue. Goals are likely to be set at all levels from the company or local region to national to global. Some will be voluntary. Others will be state or national regulations or agreed in international treaties. In some cases, goals will emerge out of agreement on more basic principles. One model is the "system conditions" proposed by The Natural Step. This group urges adoption of a scientific framework for decisionmaking within the limits of the biosphere that, for example, calls for not producing substances such as toxic chemicals at rates faster than they can be broken down in nature and a fair and efficient use of resources to meet human needs.[66]

Three important areas for setting goals are closing, dematerializing, and detoxifying the product chain.

- *Close the product cycle*. The European Union is likely to drive goal-setting for closing the cycle downstream through a draft directive that proposes to set ambitious reuse and recycling targets for classes of electronic products and assign responsibility to the producers for meeting them by 2004.[67] In the United States, some computer and electronics companies are setting targets to increase the amount of material recycled and used in their products. Xerox showed how goals that lead to reusing parts can reduce the demand for virgin raw materials and also save significant costs.

- *Dematerialize: Use material more efficiently*. This is an arena in which the electronics industry excels as it drives down product size and substitutes virtual reality and electronic communication for more material-intensive product development and transport. However, the gains have not been systematically tracked. Analysts and advocates in Austria, Germany, and the Netherlands are exploring the usefulness of goals calling for factor 4, 10, or even 50 reduction in material use per unit of economic service. These proposals are also framed as goals for dematerialization or resource productivity.[68] An OECD analysis notes that a factor 10 goal might be useful in mobilizing political support but would be only loosely related to specific environmental problems other than global warming.[69] Most activity in the U.S. computer and electronics sector on materials efficiency is at the company or sub-sector level. For example, some printed wiring board companies are benchmarking their use of materials and energy.

- Because *water* supply varies by region, water issues are being addressed locally and regionally by sub-sectors that are heavy water users, particularly semiconductor manufacturers. Environmental groups such as the Silicon Valley Toxics Coalition advocate a goal of closed water cycles at these production facilities.

- Much attention in setting goals for *energy use* has focused on products as the most energy-intensive phase. This is the area where product standards have been agreed and met. As greenhouse gas reduction targets develop, however, additional types of goals on energy use are likely to be needed. Electronic products now account for a quarter of residential energy use and are growing.[70] Goals will also play a role in reducing energy intensity of production processes in semiconductor manufacture. The electronic sector has stated in its Statement of Principles on Global Climate Change that the "industry is currently making a positive contribution to prevent pollution and reduce emissions of greenhouse gases in all facets of its operations, including the design, manufacture, use, and management of our products and the delivery of our services." It also notes: "Electronic products can play a significant role in helping society reduce greenhouse gas emissions and conserve natural resources . . ." [71] These statements could be supported by specific goals for reduction of greenhouse gases focused on major areas of application such as transport, building management, or teleworking.

- *Detoxification..* A major reason for environmental policy concern about the electronic product stream is that it introduces toxic chemicals into the environment through its waste stream. In some cases, toxic chemical goals may mean targets for phase-outs. The EU directive for electronic wastes proposes to phase lead, cadmium, mercury, and hexavalent chromium out of use in electronic products. As a goal for product and process stewardship, the Eco-Effiency Task Force of the U.S. President's Council on Sustainable Devlopment took a broad approach. It proposed a goal of phasing out the *release* of heavy metals or toxic compounds that persist in the environment or accumulate in biological organisms by 2000. By 2010, it called for a goal of eliminating the *use* of the most toxic substances by developing cost-effective, equally productive, and less toxic substances.[72]

- *Information about toxic effects.* A Swedish official notes that the main reason his government introduced compulsory product responsibility for electric and electronic product is because "developers of electronic products are introducing chemicals on a scale which is totally incompatible with the scant knowledge of their environmental or biological characteristics. . . The manufacturers themselves do not always know or care which materials the components contain."[73] Recent analysis by U.S. EPA has shown that only 7 percent of high production chemicals have a complete set of screening test data. Nearly half of 2800 or so high production volume chemicals have no test data.[74] Electronic manufacturers may also use chemicals made in smaller amounts not on this list. Thus the computer and electronics sector might examine to what extent chemicals they use have screening test data and set a goal of using only chemicals that have been screened.

### 6.2.2 Using public performance data to provide accountability

Electronics technology has greatly increased the potential of using transparency, (i.e.making information public), as a means of providing accountability for meeting goals. Transparency is already being widely used as a means of accountability in finances, crime and weapons control. The extent that this tool will be used is part of the debate on how privacy and intellectual property should be protected on one hand and information shared widely on the other.[75] Standardized public reporting on the amounts of releases of toxic chemicals by industrial facilities--combined with public accessibility through the Internet--has demonstrated the utility of transparency as a tool to stimulate action in the environmental arena in the United States. European countries have combined a requirement for a public report of environmental performance with third party certification in their Eco-Management and Audit Scheme for environmental management. U.S.

electronic companies generally prefer self-certification to avoid the costs and potential delay in certification by a third party.

Despite major issues about data quality, confidentiality, and security, public reporting is likely to play a significant role in any new framework for the computer and electronics sector as well as environmental policy more broadly. The issues in using public, electronic data to provide accountability are still being defined. Many sector players are at the stage of reacting. Others are involved in projects to develop templates that would provide better information more easily to all te stakeholders. The process of developing standard data categories is occurring in at least three areas: reports issued by companies for investors and others, regulatory information, and materials flow data at the sector level.

- *Preparing comparable company environmental reports*. Organized by the Coalition for Environmentally Responsible Economies (CERES) with technical assistance from the Tellus Institute, the multistakeholder Global Reporting Initiative aims to develop core elements of worldwide standardized corporate sustainability reporting and issue a report by March 1999.[76] A major audience is the investment community. Core data may include information about the source as well as volume of materials and energy used. The World Business Council for Sustainable Development (WBCSD) is emphasizing efficiency data in its developing core data set. In a World Resources Institute report, Ditz and Ranganathan proposed a set of four indicators addressing materials use, energy consumption, nonproduct output (all wastes and emissions before recycling, treatment, or disposal), and pollutant releases including toxic chemicals and greenhouse gases.[77] Both WBCSD and WRI are also working with the Global Reporting Initiative.

- *Making existing facility data more accessible and usable while increasing the efficiency of reporting*. The Computer and Electronics Subcommittee of the Common Sense Initiative is working on a proposal for facility-based reporting called the Comprehensive Uniform Report on the Environment (CURE). In contrast to the CERES work, it is aimed at making existing regulatory reporting more efficient and more accessible. It would combine 13 reports required under current legislation, including the Toxics Release Inventory. However, the CURE is also based on an assessment of information needs. Thus, it will also include some additional data reported on a voluntary basis or provided by the government agency. The report would be organized by material flow through the company starting with data on material characteristics and effects and continuing to cover incoming material, storage, process, recycling and energy recovery, and waste handling.[78] Companies would also have the opportunity to report information on natural resource use. The intent of the CURE is to establish a database to make the information easily accessible to a wide range of users including the companies themselves, government, and communities. Although members disagree on the need for including some data elements, for instance on demographic patterns and material throughput, the report does provide a structure for data that goes beyond making it accessible in one place and therefore should make it more useful to companies, communities, government, and others.

- *Estimating trends in sector material flows*. A third approach is estimating the volume of major material flows at the sector or sub-sector level and characterizing them by velocity, quality, and mobility, as described in section 5. These data could be used to track trends and flag areas for improvement. WRI is working with institutes in other countries to develop material flow indicators.[79]

Developing and using public metrics may be the most effective tool for providing accountability for many different kinds of environmental goals for the product chain. The Environmental Defense Fund has proposed a way to use transparency to encourage development of better information on effects of chemicals, given the large number of untested substances in use. Roe and Pease suggest creating an Unstudied Chemicals Inventory that would require companies to report on the quantities of unstudied chemicals released to the environment.[80]

Another tool that may evolve to play an important role in providing accountability is third party certification. In Europe it is combined with a public report for a facility, for example. Many companies think it is too expensive and time-consuming and provides little added value. They prefer self-certification. More experimentation will be needed to work out what combination of public reporting and certification works most effectively for the range of stakeholders in different circumstances and countries.

### 6.2.3 Apply design for environment and leverage the supply chain

The disk drive case study suggests that leveraging the environment along the supply chain will require companies to take a more strategic approach to design for environment and to develop methods to communicate environmental information along the chain.

The practice of design for environment has developed largely from the ground up among environmental staff and design engineers. It has not yet reached the business managers in most companies. The disk drive case study emphasizes the need to engage them. Clearer environmental goals and the further use of environmental management systems are two ways to move toward more strategic approaches. However, increasing knowledge about sustainability issues and the possible revenue opportunities they offer may be most important. One model is a two-day session on sustainability as a business opportunity organized by Hewlett Packard in September 1998. Over one hundred employees from across the company labs, business units, and corporate staff participated in the session that combined staff organizing with leadership by managers in laying a foundation for culture change in the company. Another approach, suggested in the Electronics Working Group discussion of the disk drive case study, is short courses involving top business leaders and academics to highlight the organizational and communication changes needed to move toward considering the environment an opportunity rather than a constraint. Such courses can be complemented by articles in widely-read business magazines.

So far communication along the chain about the environment happens mainly through check lists that customers send their suppliers to be sure that their products comply with regulations. However, other models are developing that could provide information about a product's environmental characteristics. Nortel has convened workshops with its suppliers in Europe to examine how it is viewed as a source of environmental information and plans to bring that approach to North America in the next year.[81] IBM has long used product environmental profiles as a communication device. IBM's profiles are increasingly being focused on product components. Cost and confidentiality are barriers to moving back up the supply chain to obtain environmental information. IBM has dealt with these issues by paying for consultants to help suppliers obtain the needed environmental information and ensured that suppliers can protect proprietary data.[82] A broader approach at the sector or sub-sector level that also involves NGOs may be an effective complement to the work of individual companies. For example, groups working with indigenous peoples have information about consequences of activities upstream and can help make the connection with companies using these materials.[83] European take-back and eco-labeling policies are spurring creative ways of recording and communicating environmental information about products. Options need to be developed, tested, and evaluated and standard forms developed in the next few years.

Some companies are taking the lead in working with their suppliers to incorporate design for environment in supplier practices. With support from the Dutch government, Philips has developed design for environment guidance that can be incorporated in environmental management systems. It plans to work with its plants and suppliers around the world to encourage use of this guidance.[84] However, other companies point to obstacles in working along the supply chain including the numbers of suppliers, changing relationships, locations in different areas of the world, fear of delay and increasing costs, and losses of intellectual property. Thus, other tools that increase customer demand for environmental technology are likely to be needed.

### 6.2.4 Stimulate market demand

Business members of the WRI Electronics Working Group were clear: If an important customer asks for environmental improvements in products, they will be made. Procurement and improved information for consumers are two related tools to stimulate this demand. Economic incentives that increase energy and material costs can also shift demand from energy- and material-intensive products to environmental technology.

With information technology accounting for as much as half of capital investment by firms and public institutions (more in service firms such as banking and insurance), *procurement combined with labeling* can be an important lever. Three continuing points of contention are whether a program should 1) focus on a single product attribute or multiple attributes; 2) set levels so most companies can qualify or at a level to reward only a top few companies; 3) require third party certification or allow self-certification. Who develops and administers the programs and their scientific bases are other issues.

Government procurement has been used with considerable success with labeling in the single-attribute U.S. Energy Star program for office equipment with considerable success. In contrast, the European Union's ecolabeling program agreed on criteria for a computer label in July 1998. It chose a multi-attribute approach that includes energy consumption, life-time extension, and take-back and recycling. It will require an environmental declaration that follows a model developed by the European Computer Manufacturers Association. While government procurement is an incentive for adopting the label, Dell, which is expected to apply for the label, sells its computers direct to customers. Its European manager says: "we get the customers talking direct to us and we're hearing the environmental message loud and clear." So far its process of making products to order has not interfered with verification processes in meeting national ecolabels in European countries, the company says. Samples are tested followed by random checks in the marketplace.[85] WRI Electronics Working Group members noted the influence that exposure to European practices was having on company thinking.

As businesses move to asset management of information technology, it may replace procurement as a major lever. Asset management programs are driven by customer desires to reduce costs and yet stay on the edge of technology development. Commercial firms are beginning to pay attention to waste from information technology as storage areas fill with old equipment and costs of staying on the cutting edge are recognized. Environmental issues need to be incorporated as a significant aspect of asset management. So far, they are not a major consideration.[86] One well-known model comes from Xerox. The company used leasing and asset management to achieve ambitious environmental goals in manufacturing, such as 90 percent reduction in wastes and in air emissions as well as achieving several hundred millions in savings in inventory, raw materials, and logistics costs.[87]

A fundamental change in costs is perhaps the most important step toward changing customer demand. In the longer-term, a resource-based tax may help make this shift. Redefining Progress has proposed that the tax system be redesigned to replace taxes on work, innovation, and capital formation with taxes on pollution.[88] The electronics sector should benefit from such a tax as a relatively small producer of pollution. An energy tax could also increase demand for electronic products that enable electronic communication. Of course, it could also raise some costs of producing products such as manufacture and transport. More analysis will be needed to understand the specific effects of such a shift.

6.2.5 Support on research and environmental impacts and opportunities in the sector

Research on the environmental impacts and opportunities has played an important role in finding solutions to environmental issues in the sector through, for example, Department of Energy funding of the environmental roadmaps. Design for Environment projects are a particular priority. Their results are to support other parts of the framework such as goal-setting and leveraging the supply chain. Some important work is underway. One example is the current EPA-electronics industry project on computer displays that will identify the relative environmental impacts of components and examine opportunities to eliminate toxic materials and minimize waste. However, only a very small portion of research in this sector based on innovation is focused on environmental issues. And adoption of environmental improvements is slow. Given the break-neck pace, any change that might slow the launch of a product is difficult to introduce. Programs such as the proposed Climate Change Technology Initiative are needed to shift the scale of effort in environmental technology. This five-year initiative would put six billion dollars into developing and deploying energy efficient technologies.

Another focus for research is improving understanding of the environmental impacts and benefits of electronic communication. One step might be scoping the potential benefits of electronic business (reduced use of paper?) and impacts (increased delivery?) followed by the development of guidance for realizing the benefits and avoiding the impacts. Further work is also needed on realizing the environmental benefits of electronic communication in telework. Telework is expected to reach as much as a quarter of the work force by the year 2000. It is being driven mainly by the opportunity for reduced real estate costs and increased worker satisfaction. Ways of measuring environmental benefits and policies for achieving them need to be developed as part of achieving climate goals. This task might be one focus for a working group of key players in communities, regional planning, city officials, transport, and electronic communication. So far those planning physical spaces and virtual spaces have had relatively little exchange.[89]

Opportunities to share data and policy research that are beginning to emerge across business, government, and NGOs need continued attention. Some participants in the Greening of Network session, for example, noted the need for an international database of policy research on environment and the electronics sector. IEEE may provide a forum for policy as well as technical exchange at its annual symposia on Electronics and the Environment.

6.2.6 Build broader participation in making sector environmental policy and in using electronic technology to protect the environment

Fundamental to a framework to stimulate environmental technology in the computer and electronics sector is much broader understanding of how the environment and the networked world--the real and the virtual--meet. No policies are likely to be effective if a majority of the public is unaware of the relationship and policymaking is missing key participants. Three examples of the many ways that the environmental and social goals of this increasingly pervasive technology can be further developed are the Common Sense Initiative, the Loka Institute, and software providing individuals feedback on their use of material and energy.

EPA's Common Sense Initiative (CSI) convened a Subcommittee on the Computer and Electronics Sector that included representatives of environmental and equity groups as well as of business. Though frustrating to all participants, given clashing expectations of rapid regulatory relief and environmental gains, the Subcommittee developed principles and reviewed experience on the engagement of companies and communities and workers around sector production facilities.[90]

The Loka Institute demonstrates potential directions for influencing technology research. It aims to make research, science, and technology more responsive to democratically decided social and environmental concerns. It is laying the groundwork for nationwide citizen panels after a pilot on telecommunications policy. It is arguing for broader participation in making policy and for larger funding of research in which communities participate and use the results. Its study of community-based research points out that for the United States to have the same proportion of community research centers as in the Netherlands, it would need 645 centers rather than the 50 now operating.[91]

Individuals and communities need better information on how their activities affect the environment if they are to demand greener products and use them in ways that reduce environmental impacts. Several examples of ways to use information technology to provide useful information come from Europe. A British group called Going for Green offers an EcoCal software program that allows an individual, company, or public body to measure impact in seven areas including transport, energy, water, shopping, house and garden, waste, and community action. It uses the amount of land needed to support these activities as the common metric or footprint.

Evaluation of an earlier personal environmental review in the Netherlands found that more than half of those who tried a similar review make changes in their practices[92]. In Germany, several projects have used data networks to create "virtual resources". Studies show that resource use can vary as much as four to one in the same building. Information is provided to residents through their computer or television about their use of energy along with comparisons of levels used by people in the same situation and ways to reduce use.[93] In these approaches, electronic technology provides the mechanism for learning and often also contributes to the methods of reducing environmental impacts.

In the United States, the Center for Neighborhood Technology in Chicago is exploring how to use electronic technology to achieve environmental (climate protection by aggregating smaller sources or providing financial advantages for mortgages near public transport), social (banking services for the poor), and economic goals (business opportunities for electronics manufacturers).[94] Research needs to focus on ways to use electronic technology to achieve combined economic, social, and environmental goals. Business is clear that to be successful environmental technology must be superior in both the way it performs its function and in its envrionmental characteristics. Mitsubishi Motors notes that some customers choose power over fuel efficiency. Thus they combined introduction of thier gas direct injection engine, which uses electronic technology to reduce carbon dioxide emissions by 30 percent, with a ten percent increase in power.[95] Particularly as computers and electronics move mainstream with less expensive equipment and easy access to the Internet, much more debate on "why" and "what for" questions will be needed to drive the development of technology that serves intertwined equity, economic, and environmental goals.

**Conclusion: A Vision of 21st Century Policy for the Computer and Electronics Sector**

Looking through the lens of the computer and electronics sector suggests a vision of environmental policy in the 21st century. It will focus on the product chain. Regulations governing production, one key step in the chain, will be streamlined and strengthened by tilting toward prevention. Policies for products will take the form of environmental goals that turn the product chain into a cycle that uses material, energy, and water much more efficiently and avoids toxic materials. Some goals will be set by international treaties or regional agreements given the international scope of product chains.  Some will take the form of regulations at levels from local to state and national while others will be voluntary.

The goals will be applied through performance standards and accountabiity will be provided by public reporting and/or third-party certification. Much better environmental information about products will be developed and communicated up and down the product chain. Community advocacy groups will form regional and international networks to track and compare company performance and use that information in economic development decisions.  Consumers will have the information to make decisions based on a rough environmental budget. Companies will use their innovative skills to design products that deliver better function, lower costs, and more environmental protection both because they are committed to doing so and because their customers demand it.  Revenue opportunities will drive a significant portion of a company's relationship to the environment. Economic incentives will reinforce these actions as material and waste, rather than innovation and work, are taxed.

A significant portion of research funds will be used to design environmentally-superior technology and develop longer-term changes in technology needed to meet environmental and social goals.  The direction of technology will be influenced by a much wider portion of society.  When the public is polled on the relationship of the computer and electronics sector and the environment, a majority responding will be aware of both the benefits and problems.

1. Stuart Hart, "Beyond Greening:  Strategies for a Sustainable World", *Harvard Business Review*, January-February 1997, p. 74.

2. United Nations Environment Programme, "What is Cleaner Production and the Cleaner Production Programme?"  *Industry and Environment*, Oct.-Dec. 1994, p. 4.

3. U.S. EPA, Enforcement and Compliance Assistance, *Profile of the Electronics and Computer Industry*, September 1995.

[4.] See stories , editorial and timeline on the "history of semiconductors and their toxins" in *USA Today*, January 12 and 13, 1998.

[5.] *Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness*, April 1996, http//nii.nist-gov/pubs/000-rd/challenges.html.

[6.] Tom Quinlan, "Disk drives face war of attrition," *San Jose Mercury News*, November 26, 1997.

[7.] Michael Flatt, *Printed Circuit Board Basics*, San Francisco: Miller Freeman Books, 1997, p. 2.

[8.] "Rep. Crane introduces IPC actual depreciation bill in US House", *Relay*, The Institute for Interconnecting and Packaging Electronic Circuits, December 1997.

[9.] Steven E. Prokesch, "Unleashing the Power of Learning: An Interview with British Petroleum's John Browne," *Harvard Business Review*, September-October 1997, p, 146.

[10.] Zina Moukheiber, "A hail of silver bullets," *Forbes*, January 26, 1998, p. 76.

[11.] Nathan Myhrvold, "The Dawn of Technomania," *The New Yorker*, Oct. 10-17, 1997, pp. 36-37.

[12.] Paul Krugman, "Why most econmists' predictions are wrong", *Red Herring*, June 1998.

[13.] "Just How Big is High Tech?" *Business Week*, March 31, 1997, p. 68.

[14.] U.S. Department of Commerce, *The Emerging Digital Economy*, April 1998, p. 4.

[15.] "Just How Big is High Tech? *Business Week*, p. 68.

[16.] U.S. Department of Commerce, *The Emerging Digital Economy*, p. 6.

[17.] American Electronics Association, *Cyberstates*, http://scnotes1.aeanet.org/www/ResearchStatistics.nsf/LP07a..

[18.] Moukheiber, p. 81.

[19.] American Electronics Association, *Cybernaton*, http://sc-notes1.aeanet.org/www/Research.

[20.] Chito Salazar, Semi-conductors from the Philippines, prepared for the United Nations Environment Programme, Draft as part of electronic conferece on Instruments of Change, Global Product Chains: Northern Consumers, Southern Producers, and Sustainability, http://iisd.ca/susprod/semicon.htm.

21.
E.E. Ferrey, quoted in James J. Mitchell, "A valley hero readies to retire," *San Jose Mercury News*, Jan 20, 1985, cited in Annalee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge: Harvard University Press, 1996, p. 48.

22.
Flatt, *Printed Circuit Board Basics*, pp. 1-5.

23.
Elisabeth M. Kirschner, "Electronic Chemicals," *Chemical and Engineering News*, November 24, 1997, p. 25.

24.
"Creating a Bonanza for Color Toners," *Chemical Week*, January 21, 1998, p. 39.

25.
Barbara Stallings, editor, *Global Change, Regional Response: The New International Context of*

*Development*, Cambridge, UK: Cambridge University Press, 1995. See particularly chapter 4 on Global Production Systems and Third World Development by Gary Gereffi.

26. Wirthlin Worldwide, National Quorum, August 22-31, 1997, N+a,040 adults nationwide, *The Polling Report*, October 13, 1997.

27. Conrad T. Sorenson, Business Issues Having Environmental Health and Safety Ramifications in the Semiconductor Industry, February 12, 1996.

28. See, for example, *Intel Inside New Mexico: A Case Study of Environmental and Economic Injustice,* SouthWest Organizing Project, Albuquerque, New Mexico, 1995, and *Sacred Waters: Life Blood of Mother*, prepared by the Electronics Industry Good Neighbor Campaign, 1997, which provide the perspective of community groups.

[29.] SIC 367, Electronics Industry & 33/50 Program, EPA Office of Pollution Prevention and Toxics, no date.

30. Jan Mazurek, *Making Microchips: Policy, Globalization, and Economic Restructuring in the Semiconductor Industry,* Cambridge: MIT Press, p. 120. In press.

31. Elizabeth Cook, *Ozone Protection in the United States*: *Elements of Success,* World Resources Institute, 1996.

32. See "Carnegie Mellon University Updates Computer Disposition Data," EPR2 Update, Summer 1997. http://www.nsc.org/ehc/epr2/cmu_dat.htm. Also chapter on disposition in *1996 Electronics Industry Environmental Roadmap*, prepared by The Microelectronics and Computer Technology Corporation, February 1996.

[33.] Personal communication, Tony Hainault, Jan. 21, 1998.

[34.] "Commission beefs up proposals on take-back of old electrical goods," *ENDS Report* 283, p. 43.

[35.] See, for example, Chris Robertson et al., Strategies to Improve Energy Efficiency in Semiconductor Manufacturing, presented at 1997 ACEEE Summer Study on Energy Efficiency in Industry, July 9-11, 1997.

[36.] Brian J. Johnson, Environmental Protection Agency, Global Change Division, Energy Star Computers Briefing, Washington, D.C. Cited in Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computer Industry, March 1993, p. 17.

[37.] U.S. Department of Energy, Scenarios of U.S. Carbon Reductions. Prepared for the Office of Energy Efficiency and Renewable Energy, September 22, 1997.

[38.] Moukheiber, p. 80.

[39.] *IBM and the Environment, A Progress Report*, 1997.

[40.] R.B. Johnson Dies; Disk Drive Inventor, *Washington Post*, September 20, 1998.
[41.] *Environment & Well-Being, IBM Progress Report*, 1998, pp. 2-3.

[42.] http://www.epa.gov/appdstar/buildings/

[43.] David Rejeski, "An Incomplete Picture," *The Environmental Forum*, September/October 1997.

[44.] *IBM and the Environment, A Progress Report, 1997*.

[45.] SustainAbility, *Who Needs It? Winners and Losers*, 1995.

[46.] Jerry Kaplan, *Startup: A Silicon Valley Adventure Story*, Boston: Houghton Mifflin, 1994, p. 182.

[47.] Ronald Brownstein, "Silicon Valley Gets Potomac Fever," *Fast Company*, August-September 1997, p. 164.

[48.] See, for example, Deborah Claymon and Nikki Goth Itoi, "The Tech Offensive," *Red Herring*, June 1998, p. 79.

[49.] Appendix III, The Silicon Principles, in SouthWest Organizing Project, Albuquerque, New Mexico, 1995.

50.
Riva Krut, Sustainable Industrial Development: A Benchmark Evaluation of Public Environmental Policies and Reporting in the Electronics Industry, prepared for EPA Office of Policy Planning and Evaluation, Industry Strategies Divison, November 1997.

51.
Cindy Langlois, Consumers Union, presentation at EPR2 Conference, April 1997.

52.
Telecommunications & the Future of Democracy, Preliminary Report on the First U.S. Citizens' Panel, http://www.loka.org.

53.
Ferrone , a former design engineer for Digital Equipment Corporation and a leader of the Institute for Electronic and Electrical Engineers "green workstation" project in the early 1990s, brought 30 years of experience in the electronics industry to the case study. He is now a consultant with the Lexington Group in Massachusetts.

54.
Tom Quinlan, "Disk drives face war of attrition", *San Jose Mercury News*, November 26, 1997.

55.
The constantly changing nature of the sector is demonstrated by the changes for these companies during the duration of this project between 1996 and 1998. Dell has more than doubled its sales. Allied Signal has made a bid to take over AMP. Motorola faces signficant challenges in its major markets.

56.
William F. Hoffman III, "Recent Advances in Design for Environment at Motorola," *Journal of Industrial Ecology*, Vol. 1, No. 1, 1997.

57.
Hart, "Beyond Greening: Strategies for a Sustainable World," *Harvard Business Review*, January-February 1997, p. 74.

58.
John Horrigan, Frances H. Irwin, Elizabeth Cook, *Taking a Byte Out of Carbon: Electronics Innovation for Climate Protection*, Washington, D.C.: World Resources Institute, 1998.

59.
Horrigan et al, p. 10.

60.
SAIC, Maps indicating the movement of economic flows, June 17, 1997.

61.
*Environment & Well-Being, IBM Progress Report,* 1998, p. 24.

62.
The session on Transforming Industrial Sectors: Electronics, was held on November 18, 1997, in Santa Barbara. It was designed and co-chaired by Patricia Calkins, Xerox Corporation, and Frances Irwin, World Resources Institute. About 30 people took part. They came from academia, business,

government, and non-governmental organizations and at least five countries.

63.

Presentations were made by Michael J. Fanning , U.S. Postal Service; Michael Lenox, Massachusetts Institute of Technology; and Bruce Paton, University of California, Santa Cruz. Although she was unable to participate, Janice Mazurek contributed a paper on Transformation of the Semi-conductor Industry.

64.

See, for example, Dan Fiorino, Environmental Policy as a Learning Process, draft paper, 1997.

65.

Cook, *Ozone Protection in the United States: Elements of Success*, pp. 2-3.

66.

Oregon Natural Step Network, June 1998.

67.

First Draft, Proposal for a directive on waste from electrical and electronic equipment, 1998.

68.

Lucas Reijnders, "The Factor X Debate: Setting Targets for Eco-Efficiency," *The Journal of Industrial Ecology*, Volume 2, Number 1.

69.

OECD, *Eco-Efficiency*, 1998, p. 10.

70.

Lawrence Berkeley Laboratory, Miscellaneous Electricity Use in the US Residential Sector, *Energy Policy*, vol. 26, pp. 585-593.

71.

Statement of Principles on Global Climate Change, March 1998, in Horrigan et al., in *Taking a Byte Out of Carbon: Electronics Innovation for Climate Protection*, p. 43.

72.

Eco-Efficiency Task Force Report, President's Council on Sustainable Development, Washington, D.E., 1996.

73.

"Commission Favors Development of Directive to Address End-of-Life for Electronic Goods". *International Environment Reporter*, December 10, 1997.

74.

Andrea Foster, "Scope of Testing Narrows for HPV Chemicals," *Chemical Week*, August 12, 1998.

75.

See, for example, Ann Florini, "The End of Secrecy," *Foreign Policy*, Summer 1998, and David Brin, *The Transparent Society*, Reading, Mass.: Addison-Wesley, 1998..

76.

"The Global Reporting Initiative: A Quest for Standardization", *Environmental Perspectives*, Tellus Institute, August 1998, p. 3.

77.

Daryl Ditz and Janet Ranganathan, *Measuring Up*: *Toward a Common Framework for Tracking Corporate Environmental Performance*, Washington, D.C.: World Resources Institute, 1997, p. 6..

78.

RFD Associates, Inc., CURE Form Data Elements, Draft, 5/22/98.

79.

Contact Fran Irwin at Fran@WRI.org for copies of Material Ecology Emails describing the WRI project on material flows.

80.

David Roe and William S. Pease, "Toxic Ignorance," *The Environmental Forum*, May-June 1988.

81.

Personal communication, Georges Michaud, director of environmental technology, Nortel, Sept. 10, 1998.

82.

Pathway to Product Stewardship: Life-Cycle Design as a Business Decision-Support Tool, U.S.

Environmental Protection Agency, Pollution Prevention and Toxics (7406), December 1997, p. 3-11.
83.
For example, Pacific Culture and Conservancy International in Hawaii collects data on indigenous poples affected by mining.
84.
"Philips Electronics offers guideline incorporating eco-design in ISO 14001," *International Environment Reporter*, December 10, 1997, p. 1139.
85.
"Dell poised to apply for new EC eco-label for computers," *ENDS*, July 1998.
86.
Summary of Findings, Trends in Managing Distributed Computing Resources: A Research Report Perpared by Comdisco Inc., Updated in April 1997.
87.
"Asset Management at Xerox", Box in Gary A. Davis, Catherine A. Wilt, and Jack N. Barkenbus, "Extended Product Responsibility: A Tool for a Sustainable Economy." *Environment*, Sept. 1997, p. 14.
88.
M. Jeff Hammond et al., *Tax Waste, Not Work, How Changing What We Tax Can Lead to a Stronger Economy and a Cleaner Environment* , Redefining Progress, April 1997.
89.
See, for example, Stephen Graham and Simon Marvin, *Telecommunications and the City: Electronic Spaces, Urban Places*, London and New York: Routledge, 1996.
90.
Final reports being prepared. Contact John Bowser, EPA Office of Pollution Prevention and Toxics.
91.
Richard E. Sclove, Madeleine L. Scammell, and Breena Holland, "Community-Based Research in the United States," The Loka Institute, Amherst, Mass, July 1998. Richard E. Sclove, "Better Approaches to Science Policy," *Science*, Feb. 27, 1998, p. 1283.
92.
"Consumers invited to measure their ecological footprints," *ENDS Report* 273, October 1997, p. 27..
93.
Jeffrey H. Michel, The "Virtual Power Station" in Heuersdorf, Germany, and Ecological Town Housing Development in the CO2 Model Community, Lutzschena-Stahmeln, Germany.
94.
Contact Scott Bernstein at the Center for Neighborhood Technology, Scott@crt.org.
95.
Horrigan et al. p. 23.